GEOPHYSICS

Investigation of Seismic Emission Sources in the Earth’s Crust, Japan, Northern Kanto

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This work deals with the emission activity in the upper section of the Earth’s crust. The investigation was carried out in a territory of volcanic front in the southern part of the North-eastern Japan Arc. A modification of the emission seismic tomography method, using three-component registration data [1], was employed. As distinct from [2, 3], in place of recording the amplitude with a vertical receiver, an amplitude vector projection onto the direction of particle displacement, within the longitudinal or transverse waves, was applied to the reconstruction of the medium image.

The seismic registration data obtained by the Nikko group of three-component stations were used in this investigation. The Nikko group stations are positioned in the central part of Honshu Island, at an altitude of 600–1300 m, within a sparsely-populated locality, where the industrial noise level is relatively low for Japan. The group configuration is shown in Fig. 1. Figure 2 shows the location of this area (inset) and its boundaries (dashed lines). The group consisted of 193 stations, the aperture size was about 7 km, the registration frequency band was 4.5–100 Hz. The instruments were spaced, on average, at 70 km intervals. The registration was performed in the trigger regime, the record was switched on by earthquakes having a lag in first arrivals of direct P waves of about 4 s. It is this portion of the microseismic background that was used for the construction of images. The data on earthquakes with source depths of 7–9 km were used; their epicenters and ordinal numbers are shown in Fig. 1.

The reconstruction of the emission-tomographic image was accomplished by focusing the characteristic of group directivity towards the points of the region under investigation. The scanning was carried out over nodes of the network 500 × 500 m (horizontal plane) × 1 km (depth). The algorithm of reconstruction is described in [1]. The seismic records were preliminarily checked and sorted out: on average, approximately half of the tracks, those not contaminated with exoge-

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Fig. 1. Schematic location of the Nikko seismic group (a). Triangles indicate three-component receivers; stars—epicenters of local earthquakes determined by the local network; squares and circles—epicenters, determined on the basis of longitudinal and transverse waves using the method of noise tomography; figure is the timing of Nov., 1993 earthquakes (day/hours-minutes): (1) 09/17-42, (2) 11/0-19, (3) 14/07-46, (4) 17/00-39, (5) 17/14-46, (6) 18/02-10.
15 km (depth). In this case, the initial two-layered model of the medium was used: in the upper layer, 1.6 km thick, the velocities of longitudinal and transverse waves are \( v_p = 5.2 \text{ km/s} \) and \( v_s = 3.06 \text{ km/s} \). For great depths, \( v_p = 5.9 \text{ km/s} \) and \( v_s = 3.4 \text{ km/s} \).

To test the acceptability of the model, we determined the source locations for four earthquakes from the records of first arrivals of longitudinal and transverse waves by using the emission tomography method. Their epicenters are shown in Fig. 1. The discrepancies are equal to 1-2 km, which corresponds to the error of the standard procedure for determining source coordinates in the regional catalog. The epicenters of N3 and N4, determined by us, have equal displacements. The discrepancies for the epicenters of earthquakes N1 and N2 in the P and S waves are less and are irregularly distributed. Hence, it can be concluded that the inhomogeneity of the medium, unaccounted for by the simplified model, results in spatial distortion of the image, the horizontal discrepancies being about 3 km.

The layer-by-layer seismoemission image of the medium volume investigated in the transverse waves, corresponding to the time moment preceding earthquake N4, is shown in Fig. 3. Each picture of this image represents the extension of the area of observations—the boundaries of which are indicated by the dashed lines in Figs. 1 and 2—by 12 km in the eastern direction. The power of sources in Fig. 3 is marked by the brightness of their images, and the quantitative characteristic is determined by evaluating the ratio of power of spatially coherent endogenous radiation at the surface to the power of surface interference expressed in a percentage. In this case, the 95% confidence interval is 0.15, and the exceeding of this threshold is an indication of the evaluation significance.

The characteristic features of this image are:

- the inhomogeneity of spatial distribution of the sources, which are concentrated within the central and eastern parts of the volume under investigation throughout the whole depth range from 2 to 15 km;
- the absence of any substantial radiation in its northeastern part, corresponding to the zone of weak seis-
micity, i.e., the zone of concentration of weak earthquakes, the location of which is shown in Fig. 2.

The distinction between the images at the zero depth (the sealevel, i.e., approximately 1000 m below the day surface) and at the 2-km depth is methodically important. This distinction testifies to the result independence on the distribution of near-surface sources. At the same time, the image correlation with depth is good: the central spot is clearly traced within the range 2–15 km, while the eastern one is registered within the range from 6 to 15 km.

Other images corresponding to earthquakes 1–3, 5–6 are somewhat different, which points to their temporal variability, but the main features typical for the noise specimen before earthquake N4 are preserved. The projection of the “noisy” volume onto the surface, situated at a depth of 2–15 km, is shown in Fig. 2 as region I. The seismoemission image for the noise before earthquake N1 with the source located within the “noisy” region displays a relatively weak radiation from the source zone. This may be considered to be a manifestation of seismic calmness a few seconds prior to the earthquake.
The sources of powerful historical and present-day earthquakes are confined to "noisy" region I, distinguished by the authors. This confinement may be interpreted as a reflection of high tectonic activity of the volume in question and as a cause for the formation of areas with intense tectonic displacements.

From the results of tomographic investigation of this area, it is known that a region of decreased velocities (the contrast is up to 10%) and increased attenuation of seismic waves \( Q_p \approx 80-160 \) is situated east of the Nikko group at depths ranging from 0 to 10 km, which is an indirect evidence of tectonic displacements within this volume [4, 5]. Investigation of the horizontal deformations distribution shows that compressive deformations constituting \((-10^{-5}) - 2 \times 10^{-6}\) are prevalent in region I [6], which points to a high seismic potential.

The reconstruction of noise portraits of the medium has revealed a peculiar narrow zone, located meridionally along the western boundary of region I, which is characterized by a relatively strong radiation of longitudinal waves, but does not betray itself by any radiation of transverse waves. The most contrasting image of this region is traced at depths exceeding 8 km. The revealed region of endogenous radiation exhibits the spatiotemporal variability, not correlated with the location of earthquake sources. For the specimen of noise before earthquake 1, the maximum emission activity is observed in the northern part of region II. One and a half days later, immediately before earthquake 2, the whole region is activated, and the emission radiation becomes most intense, then it drops. Another six days later, before earthquake 4, the radiation becomes moderate, and the brightest radiators being clustered in the southern part of region II. The central part of the radiating volume projection onto the horizontal surface coincides with the position of two tectonic fractures, while the configuration of its southern part corresponds to the geometric continuation of the third fracture, designated by A in Fig. 2.

The radiation spectrum for region II has two maxima at the frequencies 12 and 44 Hz, connected with deep-seated sources, and differs greatly from that for region I and those of longitudinal and transverse waves observed at the day surface. The quasi-periodic component of radiation can be associated either with a mutual transposition of blocks, when autooscillations caused by the "dry friction generator"-type sources [7] become possible, or with a pulsating motion of the vapor-gas fluid in weakened zones. The latter mechanism is realized, for instance, in well-known "volcanic tremors". It should be noted that during the investigation of seismic noise in southern Turkmenistan, which was carried out in order to reveal forerunners of earthquakes, it was established that, in the case of an approaching earthquake, the anomalies on the vertical component of the record appeared a few days before their appearance on the horizontal components [8]. The authors attributed this effect to the seismic radiation generated by the front of ground water seepage. In the volcanic area discussed in the present work, the temperature below 8 km exceeds the critical point for water; therefore, the gas phase must play an active role in the radiation mechanism. This observation qualitatively explains both the fact of predominant radiation of longitudinal waves within the zone, bordering region I from the west, and the autogenerating regime of the emission.

Our investigation has supported the fact that the seismic emission is a characteristic property of the Earth's crust. Some morphological features, which have not been observed anywhere previously, were revealed against the background of typical features expressed in the spatial inhomogeneity and certain temporal variability of the seismic emission. These features are: the confinement of the volume possessing the highest emission activity to the region of powerful earthquakes; the substantial difference between separate volumes in the relative intensity of emission radiation for longitudinal and transverse waves, as well as in the spectral characteristics of emitted signals; and the association of emission activity variations with the sources of weak earthquakes. In the latter case, various regularities can evidently manifest themselves, such as short-term, local calm periods within the source areas before earthquakes, a general activation after the earthquake, indistinct variations in the noise portrait of the medium, which accompany weak earthquakes.

These diversity and contrast manifestations point to the necessity of performing special (and not incidental) systematic investigations by means of noise tomography combined with seismic, geodeformational, geochemical, and hydrological observations. Areas of high seismic and volcanic activity would be most interesting objects of such investigations.

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