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GEOPHYSICS

The Central Kuril "Gap": Structure and Seismic Potential

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The method of revealing probable areas of future strong earthquakes ("seismic gaps") was first proposed with the Kuril–Kamchatka island arc (KKA) as an example [1]. The method is based on the following principle: sources of the strongest ($M \geq 7.7$) earthquakes have a significant tendency not to overlap each other. Based on this principle, potential areas of future earthquakes (seismic gaps) were established with a probability of 0.8–0.9. They were located in the southwestern, northeastern, and central parts of the arc [1].

By now, the first and second gaps have been occupied almost entirely by sources of strong earthquakes within the KKA since 1965 (Fig. 1). The Central Kuril seismic gap, which comprises the seismic earthquake sources of 1915 and 1918 and the KKA area marked by the last strongest earthquake in 1780 [2], has kept "silent" up to the present. The duration of the seismic cycle (recurrence frequency in one and the same region) of strong earthquakes for the KKA is supposed to be 140 ± 60 yr [3]. Therefore, the probability of occurrence of such an event in the Central Kuril seismic gap is very high, although the KKA is not considered a region of primary importance in terms of seismic hazard [4].

According to an alternative assumption, tectonic displacements occur in the KKA only due to "creep and shear " during slight and moderate earthquakes [5]. Therefore, the seismic potential of this gap is not high. However, the catastrophic Sumatra–Andaman earthquake (December 26, 2004, $M_w = 9.3$) showed that mankind has to pay a heavy price when incorrect assessments of the seismic potential of individual sectors of island arcs [6] are accepted without thorough investigations of the existing seismic gaps.

To study the Central Kuril seismic gap, the Russian Academy of Sciences undertook the *Kuril-2005* expedition (Cruise 37 of the R/V *Akademik Lavrentiev*) in the Central Kuril Islands region in August–September, 2005. The joint expedition of the Shirshov Institute of Oceanology and the Pacific Institute of Oceanography was carried out to study the tectonic structure of the seismic gap. The main attention was concentrated on revealing zones of transverse faults, which are supposed to bound sources of the strongest earthquakes (seismogenic blocks) and play an important part in the preparation and realization of a strong earthquake [7, 8]. The purpose of the studies was to reveal the reason for the long-lived character of this seismic gap, its seismic potential, and consequences of tsunami waves in the case of a strong seismic event in this region. The cruise set up three regional, 560–650 km long, geophysical (continuous seismic profiling coupled with bathymetric, magnetic, and gravimetric surveys) profiles across the entire seismic gap and scrutinized individual areas of the island slope (Fig. 3, inset).

Data obtained during the *Kuril-2005* expedition indicate that the structure of the Central Kuril front is anomalous for the subduction zone because of the presence of a large tension structure at the KKA front. It has been established that the Vityaz Ridge, a frontal (neovolcanic) arc, is separated into two (southwestern and northeastern) parts by normal faults (Fig. 2) that make up walls of a large asymmetrical tension structure. Its NW-striking southwestern wall represents a single fault scarp ~3 km high. The scarp also represents the southwestern boundary of the Bussol graben, the only tension structure previously known in this region [9]. The submeridional northeastern wall is made up of two scarps, each 1.5–2 km high. The central (submerged) part of the Vityaz Ridge is sandwiched between the walls. Its acoustic basement includes two inclined blocks

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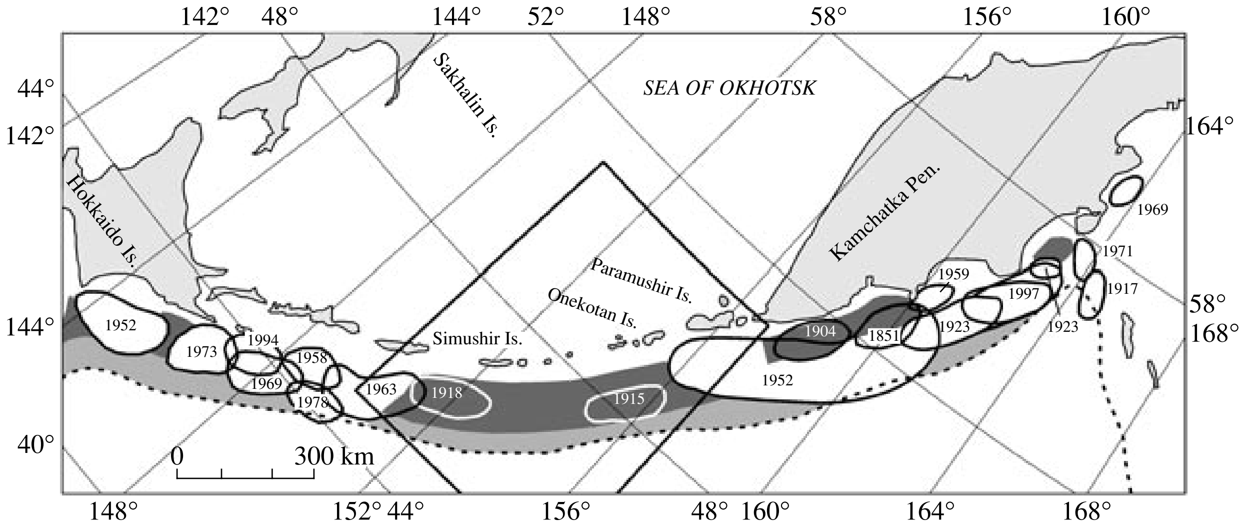

Fig. 1. Sources of strong earthquakes of the KKA and the position of seismic gaps (modified after [4]). Gray color designates possible areas of future earthquakes with $M \geq 7.7$; dark gray color shows the most probable areas of future earthquakes with $M \geq 7.7$. The dotted line designates the trench axis. Incised in the rectangular is the investigation region of the "Kuril-2005" Expedition.

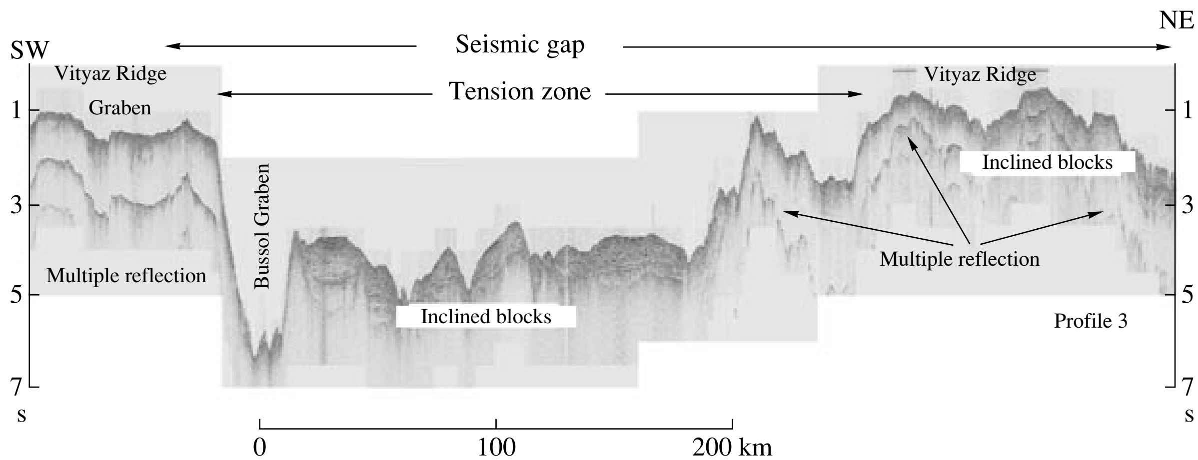

Fig. 2. Seismic profile 3 intersecting the seismic gap and illustrating the structure of the central part of the frontal slope in the investigation region. See Fig. 3 for the profile position.

that are typical for the tensile environment (Fig. 2). The magnetic, seismic, gravimetric, and bathymetric data indicate that the length of blocks in this area is ~50 km, which is several times less than the length of the source zone of a strong earthquake. The strike of separate blocks in places, where it could be established on the basis of survey data, is northwestward or submeridional, i.e., corresponds to the strike of fault scarps bounding the structure. Inclined blocks are also well seen within the northeastern fragment of the Vityaz Ridge. A small graben was deciphered at the top of the western fragment of the ridge (Fig. 2). The graben extends nearly from north to south, but data on the orientation of inclined blocks are absent.

The tensile zone has a triangular shape narrowing toward the trench, and its width (the distance from the southwestern wall to the northeastern one) in the central part of the slope is 275 km along profile 3. However, if we take into account the entire tensile area, its size will exceed 450 km, which is nearly equal to the linear dimension of the seismic gap (Fig. 2).

The lack of very strong earthquakes in this region so far is presumably related to small dimensions of the blocks. The blocks accumulate stresses relieved by earthquakes of moderate magnitudes. However, one cannot state that such a mode of seismic process will be retained here for long. There are well-known examples of the grouping of seismogenic blocks with time in the same subduction zone; i.e., the earthquake source can

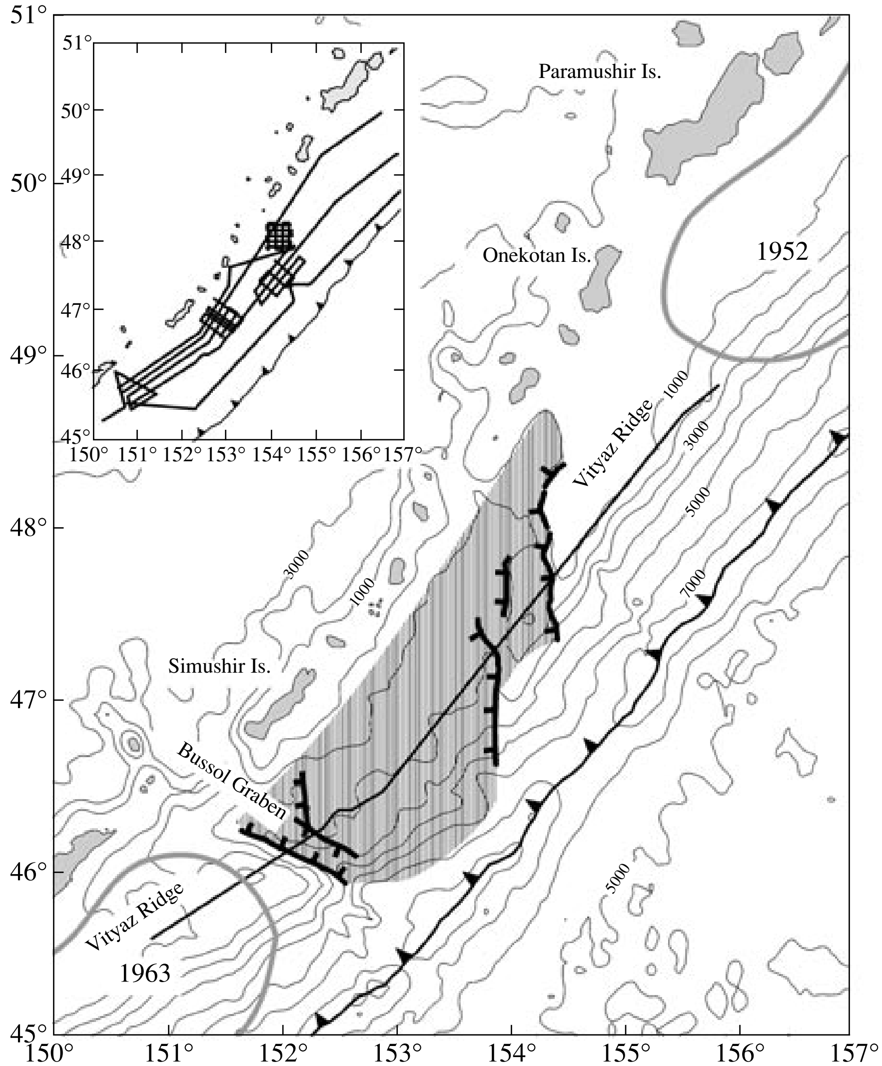

Fig. 3. The scheme of principal transverse faults bounding the tension zone (vertical striation). The seismic gap occupies the area between sources of strong earthquakes occurred in 1952 and 1963 (solid gray lines). The line shows the position of seismic profile 3. Toothed lines indicate the axis of the deep-sea trench. Isobathic lines are shown in 1000 m. The inset illustrates the position of the geophysical survey profiles.

occupy not one but several blocks, leading to an increase in the magnitude and rupture length of the earthquake. Such a seismic scenario was realized during the catastrophe on Sumatra Island in December 26, 2004. The source of this event was 1300 km long and involved several blocks [6].

The earthquake on the Kamchatka Peninsula on December 4, 1952, was the strongest one within the KKA over the instrumental observation period. The earthquake is included in the list of 11 greatest events that took place in the World after 1900 [10, 11]. The subsequent tsunami completely destroyed Severo-Kurilsk (Paramushir Island) and killed numerous people. Since dimensions of the Kamchatka earthquake source and the seismic gap are similar (Fig. 1), the maximum magnitude of the earthquake, in case the source of this event embraces the entire seismic gap (including earthquakes sources of 1915 and 1918), can theoretically be comparable to the Kamchatka earthquake magnitude (9.0).

During tsunamigenic earthquakes, the wave height generally shows linear dependence on the earthquake magnitude. In some cases, however, earthquakes may provoke anomalously high waves. One of the causes of such phenomenon is the seismogenic rupture plane slope during the earthquake: the steeper the slope, the higher the tsunami wave [12]. Investigations carried out in the central Kuril island arc have revealed the abundance of transverse faults in this area. Their displacement planes are certainly steeper than those related to overthrusts that are typical of subduction zones. Therefore, conditions optimal for the appearance of anomalous tsunamis exist in the central Kuril island arc. Moreover, since the potential separate blocks of the source of a future strong earthquake are characterized by small dimensions, we can suppose that they will act as pumps on the overlying watermass and will experience substantial vertical displacements.

Regional reconnaissance carried out during the *Kuril-2005* expedition showed that the central Kuril island arc is broken by transverse faults into a series of small blocks due to extension of the earth's crust. This is most likely responsible for the long "silence" of the region and the consequent uncertainty of its seismic potential and seismic history. However, the Sumatra–Andaman earthquake has shown that the long seismic "silence" of individual fragments of island arcs (subduction zones) may result in global catastrophes. One cannot rule out a similar scenario for the central Kuril island arc as well. Therefore, the further comprehensive study of this region is one of the paramount missions within the framework of the National Program on Prediction and Prevention of Natural Catastrophes.

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