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PREDICTION OF FUTURE GREAT EARTHQUAKE TIMES OFF KAMCHATKA AND THE NORTHERN KURILS

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On the basis of the writer's data of the migration of great 18-20th century earthquakes and their repeat times he offers a forecast of the times of large earthquakes that are likely to occur in the northern Kurils and Kamchatka during the late 20th- early 21st centuries. The evolution of a seismicity pattern in the region is suggested.

INTRODUCTION

In my previous paper [4] I described the properties of the seismic process in the Benioff zone off Kamchatka and the northern Kurils. My study was based in a large measure on the distribution of earthquakes in the Nankai trough [1]. The principal outcomes of the study are as follows.

(1) The distribution of the rupture areas of the largest (M≥7.6) 20th century earthquakes allowed me to divide the Benioff zone off Kamchatka and the northern Kurils into nine blocks and arrange them into two groups by size. One group includes the blocks off northern Kamchatka between Capes Shipunskiy and Ozernoi, ranging within 120±20 km in length. The other contains the blocks off southern Kamchatka and the northern Kurils between the Kruzenshtern Strait and Cape Shipunsky, L = 190±20 km. The northern and southern blocks differ in the magnitudes of the large 20th century earthquakes, M=7.9±0.3 and M=8.2±0.3, respectively.

(2) The rupture areas of all large 18-20th century earthquakes group into migration sequences which involve several blocks and extend along the coast of Kamchatka from southwest to northeast. The duration of earthquake sequences was < 21 years.

(3) Using the same seismological materials, I constructed earthquake sequences in which the rates of migration are opposite in sense and similar in absolute value, 4±1 km/yr on an average. The intervals between them Δt_0 range 100±20 years.

(4) I also found that the rupture areas of great Kamchatkan earthquakes that had occurred within one block tended to migrate

across the Benioff zone. The direction of the migration might be different in different blocks, the rate being 0.3-0.4 km/yr.

(5) Great earthquakes recur once in T_0=96±32 years on the average within a block, the repeat time for the southern Kamchatkan and northern Kuril blocks being T_s=106±8 years. The repeat times for the northern Kamchatkan blocks between Cape Shipunskiy and the Kamchatskiy Peninsula (blocks III-V in Figure 3 [4]) average T_n=85±40 years, the extreme subgroups being: $T_{n,1}$=124±11 years and $T_{n,2}$=46±8 years. This "splitting" of the repeat times for the northern Kamchatkan blocks and the junction of the Kamchatkan and Aleutian trenches suggests that the seismic processes in the Kamchatkan and Aleutian arcs have different repeat times.

The fact that Δt_0 and T_0 are similar may indicate that the seismic process can obviously be equally well described by models based on a 4 km/yr migration and on the recurrence of great earthquakes in a single block.

Here I use the results of the previous study to construct a scheme of earthquake prediction in Kamchatka, the northern Kurils, and the Komandorskie Islands, which will help to forecast periods of time during which great earthquakes are likely to occur in some or other block and predict their macroseismic effects.

SOUTHERN KAMCHATKA - NORTHERN KURILS

The sources of great earthquakes that occurred in 1737-1952 in southern Kamchatka and the northern Kurils (blocks VI-IX) are located exactly at the intersections of the type 1 migration sequences (migration along the Benioff zone in both directions at a velocity of about 4 km/yr). The repeat times in all blocks are similar (T_s=106±8 years). These data can be used to derive the time periods in which great earthquakes are to be expected within the southern Kamchatkan and northern Kuril blocks.

Extrapolating the migration sequences to the future, one can see that they intersect the central parts of blocks IX, VIII and VII in the years 2015, 2045, and 2006 (±10 to 20 years), respectively. These times agree with the repeat times T_s in blocks VI-IX: 2021, 2052, and 2010 (±8).

So, the evidence of type 1 migration and of the recurrence of great earthquakes within a single block indicates that large earthquakes are likely to occur in blocks IX, VIII and VII in 2018, 2049, and 2008, respectively. The uncertainty ranges within 8-20 years and averages 10 years.

The time when a great earthquake may occur in block VI can be defined as 1952+T_s = 2058±8 years.

The times of future great earthquakes in southern Kamchatka and the northern Kurils are listed in Table I.

Table 1 Times of future great earthquakes in the Southern Kamchatka - Northern Kurils region (blocks VI-IX)‡.

Time of future earthquake	*Block number*			
	IX	VIII	VII	VI
Year	2018	2049	2008	2058
Time interval, years	2008-2028	2039-2059	1998-2018	2048-2068

‡ The time intervals determined by A. Vikulin's technique contain about 50 percent of expected earthquakes and 90 percent when they are doubled. - Ed.

NORTHERN KAMCHATKA - KOMANDORSKIE ISLANDS

The rupture areas of great Kamchatkan earthquakes in blocks I-V and near the Komandorskie Islands do not lie exactly at the intersections of the type 1 migration sequences. For this reason the times of great earthquakes in the northern blocks cannot be determined with certainty. However, knowing the times of future earthquakes within the southern blocks and using the data on the type 2 migration sequences (migration along the Benioff zone from SW to NE with sequence durations below or equal to 21 years) and on the data on the recurrence of great earthquakes in blocks I-V, the evolution trend of the seismic process can be outlined.

Great earthquakes cannot occur in the northern Kurils and southern Kamchatka earlier than 1998, as has been pointed out above. The duration of a type 2 migration sequence ranges within 0-21 years. Hence a great earthquake or possibly several such earthquakes can be expected in northern Kamchatka during the years 1998-2019. The sources of these earthquakes are likely to be localized in block IV (off Kronotskiy Peninsula) or II (between the source areas of the 1969 and 1971 events), since no great earthquakes occurred there during 90 and 200 years, respectively.

In case the first great earthquake in the south of the region (northern Kurils and southern Kamchatka) will occur somewhat later than 1998 (for instance, in 2010), the probable time span for the north of the region must be shifted accordingly, 2010-2031.

It may also happen that a great earthquake in northern Kamchatka, e.g., in block IV, will occur almost simultaneously (within a few seconds to a few months) with an event in the south, in block VII or IX. Another possibility is that the seismic process may evolve as in 1792 [4]: a double shock with sources in block VII and II-III.

It is not unlikely that a great earthquake will occur outside this segment of the Benioff zone, close to Karaginskiy Island. That the seismicity migrates along Kamchatka further northeast is evidenced by

large earthquakes that occurred in 1/22/1976, 9/10/1985 and 10/13/1988 between Karaginskiy Island and Kamchatka (in Litke Strait), in the Oleyutorka Bay, and in the upper reaches of the Pakhacha River, respectively.

In the event of two nearly simultaneous shocks in southern and northern Kamchatka, the seismic process may extend toward the Komandorskie Islands. In that case, the rupture of a severe earthquake will involve a part of the Benioff zone near the line that continues the 1917 rupture zone opposite the Komandorskie Islands or beneath them, or else under the Bering Sea shelf.

MACROSEISMIC EFFECTS OF THE PREDICTED EARTHQUAKES

The areas where large (M≥7.6) earthquakes are likely to occur off the northern Kurils, Kamchatka and the Komandorskie Islands are shown in Figure 1. Also indicated are the times of the expected events. Below follow some explanations.

Assume that the source of a great Kamchatkan earthquake cannot lie west of the boundary of the Benioff zone. The situations are examined using the above evidence on the transverse migration. The macroseismic effect is assessed according to the MSK-64 scale [7] for medium-quality soils.

Block IX, 2008–2028. Only one earthquake (5/1/1915, M=8.3) is known to have occurred within that block. No data of the macroseismic effect of that event are available[a] [9]. The catalogs [5], [8] report three aftershocks only. As the rupture zone of that earthquake could not be determined with certainty, a future great earthquake may rupture any portion of the block. The maximum vibration is expected to reach intensity IX on the nearby islands Ketoi and Onekotan.

Block VIII, 2039–2059. As the second shock of the 11/4/1952, M=8.5 earthquake was located near the western boundary of the Benioff zone, the next great earthquake will most likely occur in the central part of this block or near the trench axis. The greatest macroseismic effect is expected on Paramushir and Shumshu, close to the rupture, and will not be greater than intensity VIII.

Block VII, 1998–2018. Two M=7.7 earthquakes occurred in that block with 6-hour interval in 6/25/1904; their source areas were near the western boundary of the Benioff zone, like that of the 1952 event in block VIII. Both shocks caused shaking of intensity VIII in Petropavlovsk-Kamchatskiy. The likely location of the next rupture in this block is the same as in the neighboring Block VIII. The greatest macroseismic effect is expected on the coast of Kamchatka against the rupture area and will not be over VIII. It must not produce stronger

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[a] Preliminary Report on Seismic Activity at the Site of the Kronotskiy Power Plant, Kamchatka. Petropavlovsk-Kamchatskiy, 1968. File No.8 KGS IFZ AN SSSR.

shaking than intensity VII in Petropavlovsk-Kamchatskiy.

Block VI, 2048-2068. The block is in the Avacha Bay against Petropavlovsk-Kamchatskiy. The previous large earthquakes of 1737, 1841 and 1952 in this block caused shaking of intensities IX (VIII-IX), VIII and VII in Petropavlovsk-Kamchatskiy. Accordingly, their sources must have been located progressively farther from the western boundary of the Benioff zone (oceanward from Kamchatka). This means that a transverse oceanward migration of great earthquakes took place in the Avacha block during the period of 1737-1952. As we do not know whether the 1952 earthquake was the last event in that migration cycle, two possible locations of the next great earthquake can be envisaged. One is near the trench axis with the intensity of shaking in Petropavlovsk-Kamchatskiy of VI-VII at most. The other is near the western boundary of the Benioff zone, where the 1737 event seems to have occurred. In that case shaking in Petropavlovsk-Kamchatskiy may reach IX on medium-quality soils. The data available indicate that Petropavlovsk-Kamchatskiy lies in the intensity IX zone where events of such intensity may repeat every 300 years [10]. For this reason possibility of the next earthquake within the Avacha block seems more realistic. If the epicenter happens to be located near the western boundary of the Benioff zone, shaking in Petropavlovsk-Kamchatskiy may reach intensity X on medium-quality soils as demonstrated in [6].

Block V. The nearest time of the next great earthquake according to my theory is 1998-2019. However, as the last earthquakes in this block occurred in 1923 and 1959, the next great event is not expected earlier than the later half of the next century. The location of the rupture is to be updated in the future.

Block IV. The nearest time is 1998-2019. As there are no data of a great earthquake in this block, the next event of this rank can occur in any site of the block during the time period indicated. If it occurs near the western boundary of the Benioff zone, the Kronotskiy Peninsula would be within its epicentral zone and shaking of intensity IX or greater is expected on the coasts of the Kronotskiy and Kamchatka bays.

Assuming that the last great earthquake occurred in this block in 1899 [4] and that the repeat time is $T_{n,1}$=124±11 years, the time of the next great earthquake must be 1899+$T_{n,1}$=1899+124 (±11), or 2012-2034. This period agrees with the time predicted on the basis of type 2 migration sequences.

Block III, the earliest time is 1998-2019. A great earthquake is unlikely to occur during this time period, because the last earthquakes of this type occurred there in 1923 and 1971. If it does occur, its time, in accordance with the repeat time $T_{n,2}$=46±8 years, is likely to be 1971+$T_{n,2}$=1971+46 (±8) = 2017±8, or 2009-2025. It is consistent with the time based on type 2 migration sequences. The likely location of the rupture area is near the western boundary of the Benioff zone. Ust-Kamchatsk and the entire coast of the Kamchatka Bay will be in the epicentral zone. The source location of a great earthquake in this

block was proposed earlier [2].

Block II, the nearest time is 1998-2019. There is no record of a great earthquake in this block. The geometry of the Benioff zone there is not well known. The western boundary seems to be diffuse north of Ust-Kamchatsk. A possible rupture area might be the region off the Kamchatskiy Peninsula between the source of the 1971 (block III) and 1969 (block I) events. A great earthquake thus located would produce shaking of intensity up to X on the shore of the Kamchatka Bay and IX in Ust-Kamchatsk and on the shore of the Ozernovskiy Bay.

Block I. The last great earthquake with a source in this block occurred in 1969. It is unlikely that great events will occur there during this and the next century.

The region off the Komandorskie Islands. The nearest time is 1998-2019. The most likely location of a future rupture is a strip on the continuation of the 1917 rupture area off the islands. It is not unlikely that the islands will be in the epicentral zone of a great earthquake, as is often the case for such earthquakes in the Aleutians. Ground motion may reach intensity IX or more.

SUGGESTIONS FOR EARTHQUAKE PREDICTION PROGRAM IN KAMCHATKA

At the present time earthquake prediction activity in Kamchatka is mainly focused in the area of Petropavlovsk-Kamchatskiy. This is understandable, because most of the Kamchatkan population is concentrated in this area. In my opinion however, this policy is not quite justified.

The analysis in [4] and in this paper has shown that a great earthquake off Petropavlovsk-Kamchatskiy within the Avacha gap (block VI) is not likely to occur before the middle of the next century. Much earlier, some time around the turn of the century, can we expect a great earthquake in the adjacent block VII between Cape Povorotnyi and Cape Lopatka or in block IX off Onekotan I. and Ketoi I., or else two events in both of these blocks with a short time interval between them. According to my determinations, it is advisable to intensify geophysical observations near these blocks to acquire information on the seismic process and monitor earthquake precursors. The sooner this is done, the more data will be accumulated by the time of the next great earthquake. This will enhance the chance of a timely forecast of nearest great events which are likely to start off a new period of high seismic activity in the region.

Likewise it is necessary to intensify geophysical observations near block IV (Kronotskiy Peninsula) and block II (Kamchatskiy Peninsula, southern Ozernoi Bay) which are more likely to be ruptured by future great earthquakes in northern Kamchatka. In that case, apart from more accurate and timely forecasts, we will be able to trace the propagation of the seismic process northward.

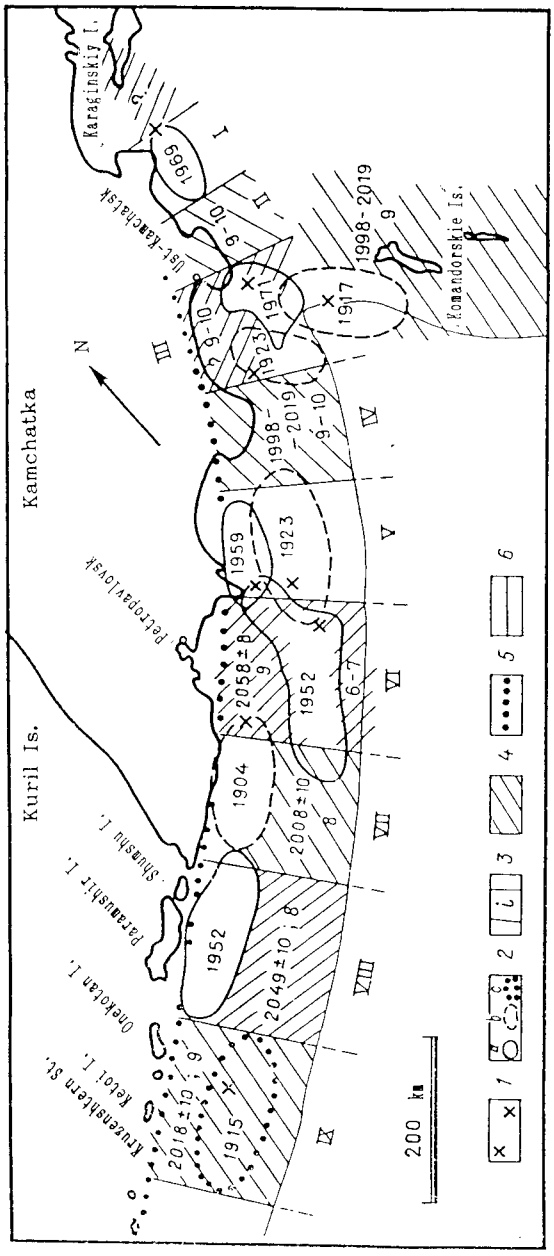

Figure 1 Map showing predicted great earthquake rupture areas in Kamchatka and the northern Kurils. 1 - great earthquake epicenters; 2 - certain (*a*), less certain (*b*) and inferred (*c*) source regions of great earthquakes in the 20th century (with the years of occurrence); 3 - boundaries between blocks of the Benioff zone, *i* = I to IX; 4 - inferred location of future great earthquakes. Figures indicate the time of an expected earthquake and its maximum intensity on land; 5 - western limit of the Benioff zone; 6 - axis of the deep sea trench.

CONCLUSION

In 1990 I proposed a phenomenological model of the seismic process based on the study of seismicity in the northwestern Pacific margin [3]. I found that the seismic process in the entire Pacific margin can be represented as seismicity waves propagating circumferentially in the opposite direction with the period and wavelength equal to the duration of the seismic cycle and the size of a great earthquake rupture area. The possibility to represent the seismicity of the entire Pacific margin in terms of a unified model will be helpful for constructing prediction schemes for the other segments of the circum-Pacific belt.

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