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SEISMIC QUIESCENCE BEFORE THE HOKKAIDO-TOHO-OKI EARTHQUAKE OF OCTOBER 4, 1994

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ABSTRACT

The Hokkaido-Toho-Oki earthquake named by JMA is a lithospheric earthquake: an intra-plate even that ruptures through a substantial part of the subducting oceanic lithoshpere, is the largest from a data set of 3714 earthquakes beneath the southern corner of Kuril Is. during the period January 1984 through 4 October 1994 from the digital recorded network run by the Research Center for Earthquake Prediction (RCEP) of Hokkaido University. We have applied the efficient, objective monitoring procedure that was developed for investigating the changes in seismicity preceding a large earthquake to the data set. There was a quiescence for the period 3 years preceding the main shock, surrounding, but not including, the immediate epicenter, and only for magnitudes $\geqq$ 3.5. This procedure for alerting one to the possible existence of a developing anomaly has potential value as a general monitoring tool.

KEYWORDS

Hokkaido Toho Oki Earthquake; Earthquake prediction; Precursory seismicity pattern; Seismic quiescence; Monitoring procedure; Intra-plate event.

INTRODUCTION

A large earthquake occurred off Shikotan Is., one of the Kuril Is., on 4 October 1994. It was named the Hokkaido-Toho-Oki earthquake by the Japan Meteorological Agency(JAM). The hypocentral parameters given by JMA are: origin time 13:22:57.2 UT, epicenter = (43.37 ° N,147.66 ° E), depth = 30 km, magnitude = 8.1. In Iturup, Kunashiri and Shikotan Is., more than 10 people were killed, many were injured and considerable damage of roads and houses was caused by shaking and tsunami.

In Hokkaido, Japan, more than 300 people were injured and extensive damage of roads and houses was caused by shaking. Strong ground motion was felt even in Tokyo, about 1000 km from the epicenter.

Seismic quiescence, a significant decrease in the rate of seismicity for a period of time in the general vicinity of a future main shock, has been reported as a seismic precursor for many moderate and larger earthquakes. In many cases, the quiescence is restricted to the focal region of the main shock. In some instances, this quiescence has been accompanied by a simultaneous increase in activity in a doughnut-shape region surrounding the quiescence zone(e.g.,Mogi,1969). Our previous paper (Taylor et al. ,1991) described and discussed the seismicity in the vicinity of the large/moderate Urakawa-Oki earthquake of M_{JMA} = 7.1, which occurred on 21 March 1982 off the southern coast of Hokkaido, Japan. It presented results that showed that there were significant anomalies in the seismicity patterns beginning about 2 years before the main shock.

In this article, we present the implications of the Hokkaido-Toho-Oki earthquake and show that there were same significant anomalies beginning about 3 years before the main shock.

EARTHQUAKE DATA CATALOG

The RCEP operates a digital seismic network on Hokkaido. Since 1976, the network has consisted of nine digitally telemetered three component stations with additional stations added after 1983. Before this telemetry was being upgraded, the catalog for the subset of the events in the magnitude 3.0 for lack of stations in the eastern part of Hokkaido. Therefore, we use the catalog for the subset of the events from 1 January 1984 through 8 October 1994 including the Hokkaido-Toho-Oki earthquake.
The magnitude scale used by the RCEP is based on signal duration and is calibrated against the JMA amplitude-based scale. Taylor et al.(1990) and Takanami et al.(1991) show that the catalog for the subset of the events they studied is complete down to magnitude 2.0 within a 50-km radius of the Carnegie broadband station at KMU(longitude 142.97 ° E, latitude 42.24 ° N) in the RCEP seismological network. Here, it is assumed that study is complete at least down to magnitude 3.0 within the region of the Hokkaido-Toho-Oki earthquake and its vicinity.

HOKKAIDO-TOHO-OKI EARTHQUAKE

The main shock occurred off Shikotan Is., one of the Kuril Is., and off the Nemuro peninsula in the most eastern Hokkaido, on 4 October 1994. The RCEP determined the hypocenter to be 43.37 ° N, 146.79 ° E, and focal depth 26km. Katsumata et al.(1995) relocated the aftershocks by using the eight P-arrival times together with at least one and more S-arrival times read at eight stations of the local seismic network of the RCEP deployed in the eastern Hokkaido. They described that one fault plane of the main event might be almost parallel to the Kuril trench and to be dipped vertically. Kikuchi and Kanamori(1995) inverted body-wave records (both P and SH components) to determined the rupture pattern in terms of

series of subevents.
They described that the source parameters are: the location of the initial break = (43.48 ° N, 147.40 ° E); the centroid depth = 50 km; the seismic moment $M_0 = 2.6 \times 10^{21}$ Nm (M_w = 8.2); fault area S = 120 × 60 km^2 ; the average slip D = 5.6 m; the stress drop $\Delta \sigma$ = 11 MPa. They also described that waveforms computed for the deeper plane fit the data better. Such results strongly suggest that the 1994 Hokkaido-Toho-Oki earthquake is a lithospheric earthquake: an intra-plate event that ruptures through a substantial part of the subducting oceanic lithosphere.

Meanwhile, JMA gives the hypocenter parameters to be 43.67 ° N, 147.336 ° E, focal depth 30 km , and magnitude 8.1.

ANALYSIS

The analysis and presentation of data related to potential quiescence precursors are complicated by the fact that the phenomenon depends upon a time, two spatial dimensions (depth is generally not considered), are possibly a limited range in magnitudes. Hence seismicity trends, which are functions of (at least) four dimension, must be presented in two-dimensional plots.
The type of projection used in presenting the data makes implicit (if not explicit) assumptions about the data that may influence its interpretation.

Figure 1(a) is a plane-view seismicity plot for the entire study period for magnitude ≧ 3.5 and depth ≦

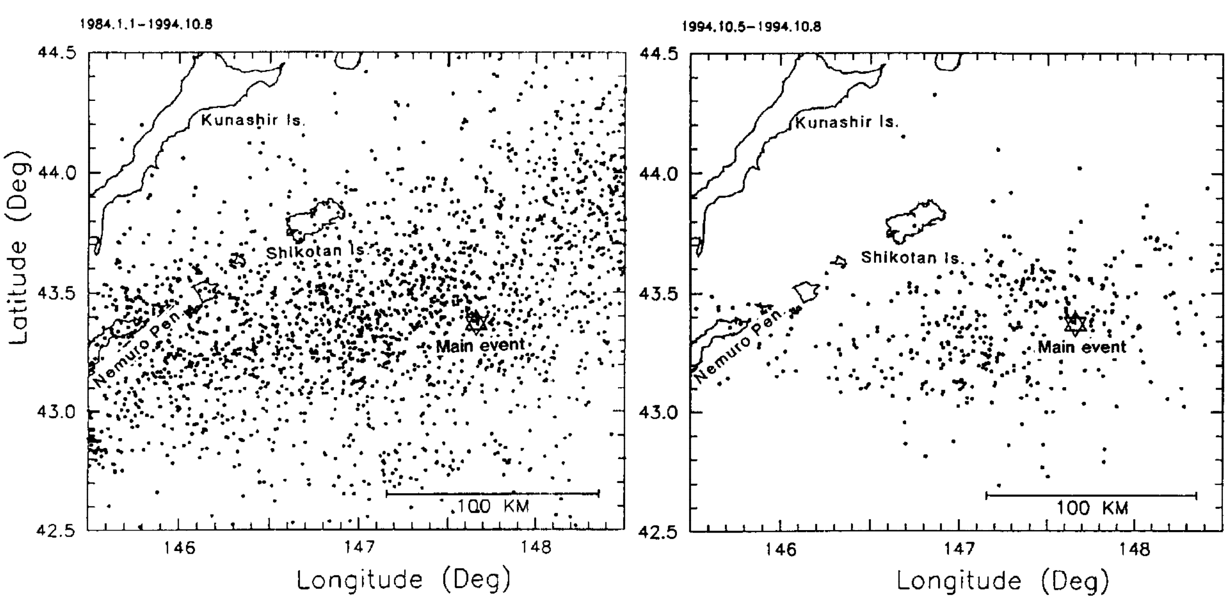

Fig.1(a) Plan-view seismicity section for the entire study period, January, 1984 through 8 October, 1994 in the depth range 0 to 100km and m ≧ 3.5.

Fig.1(b) Seismicity section for the 4 days after the main event in the same range of depth and magnitude as in (a).

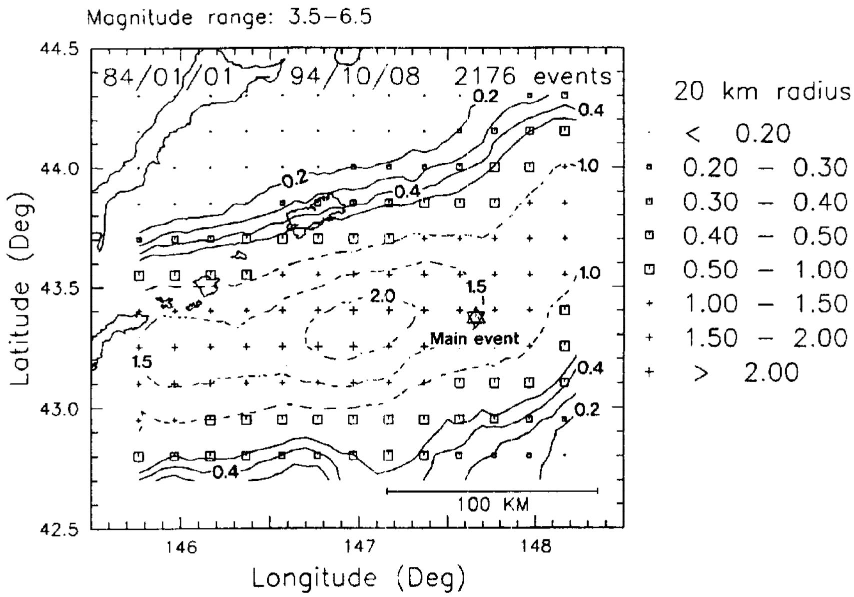

Fig.1(c) Contour of the average number of earthquakes per month for the same data. Symbols, scaled to the events/month at every third grid point, are included to aid interpretation. (No symbol means no event at that grid point.) There are two sets of contours: thick- and thin-dashed. For the thicker contours, the minimum and maximum contours are at 0.2 and 0.5 events/month, respectively, and the increment is 0.1 events/month. The thin-dashed contours have a minimum, maximum, and spacing in events/month of 1.0, 2.0, and 0.5, respectively. The eastern coast of Peninsula Nemuro with those of Kuril Is. are shown, and the epicenter of the Hokkaido-Toho-Oki event by JMA is indicated by a star. The total number of events (2176) along with the time span are included.

100km. Of the 2176 $\geqq$ 3.5 events during the whole period, 416 occurred in 4 days following the main shock (Fig.1(b)).

Taylor et al.(1991) have developed an efficient, objective contouring procedure for portraying the changes in seismicity patterns with time. The contouring procedure is flexible yet easy to use and interpret. They recommended its consideration as a tool for monitoring temporal and spatial trends in seismically active regions. The following explanation is the contouring tools.

The method we have used starts with a variant on the time-slice seismicity plots. We portray the seismicity for selected magnitude range and time periods as map-view contour plots of number of events per month.

Epicenters of all the events in selected magnitude range and time period are projected onto the nearest grid point (5-km spacing) and summed. Smoothing is done by using a center-weighted average of all events within a 20-km radius of each grid point. The smoothed totals at each grid point are normalized to give events per month. To faciliate interpretation, symbols, with sizes proportional to the average number per month, are included (with a spacing of 15 km). No symbol at a symbol grid point

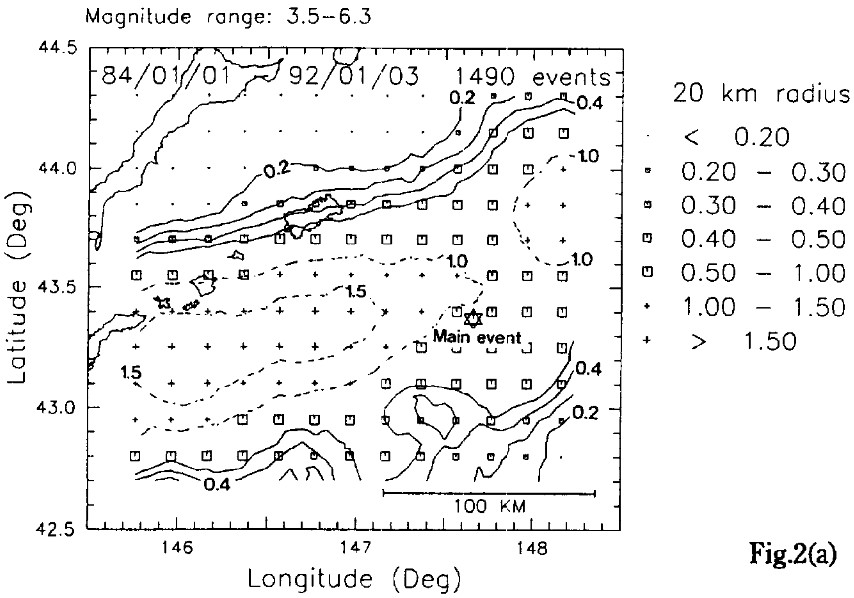

Fig.2(a)

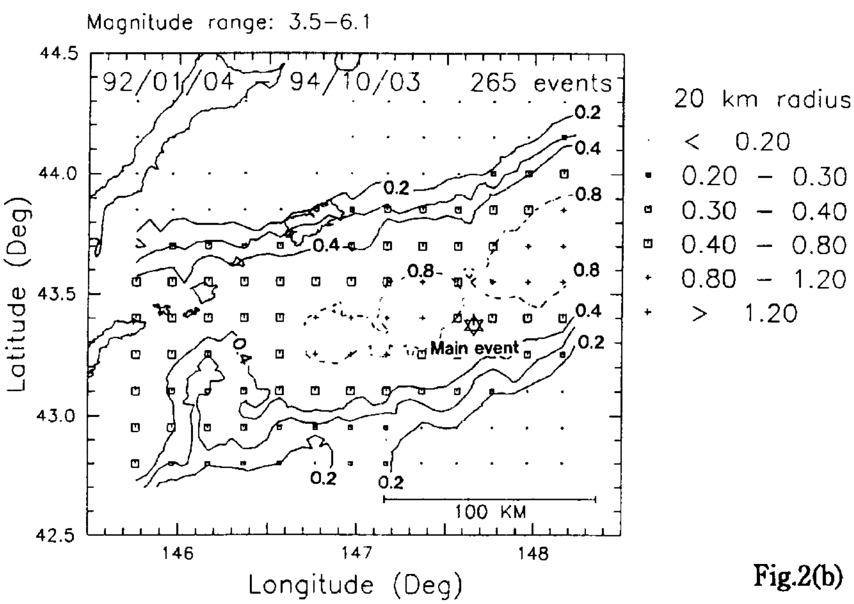

Fig.2(b)

Fig.2 Contour of the average number of earthquakes per month, as in Figure 1(c), for m ≧ 3.5 for the time intervals as indicated. The thick contours are as in Figure 1(c) with the highest countour at 0.5 and 0.5 events/month in Figure 2(a) to 2(b), respectively. The thin-dashed contours have a minimum, maximum, and spacing in events/month of 1.0, 1.5, and 0.5, respectively, in Figure 2(a) and 0.8, 1.2, 0.4, respectively, in Figure 2(b). Note the through-shaped quiescent region during the 1 January, 1992 to 3 October, 1994 period (Fig.2(b)) in opposite trend of Fig.2(a).

means no events.

Figure 1 (c) is a contour of the average number of earthquakes per month for the data set shown in Figure 1 (a). To allow one to see the spatial patterns of both the mainshock-aftershock events as well as

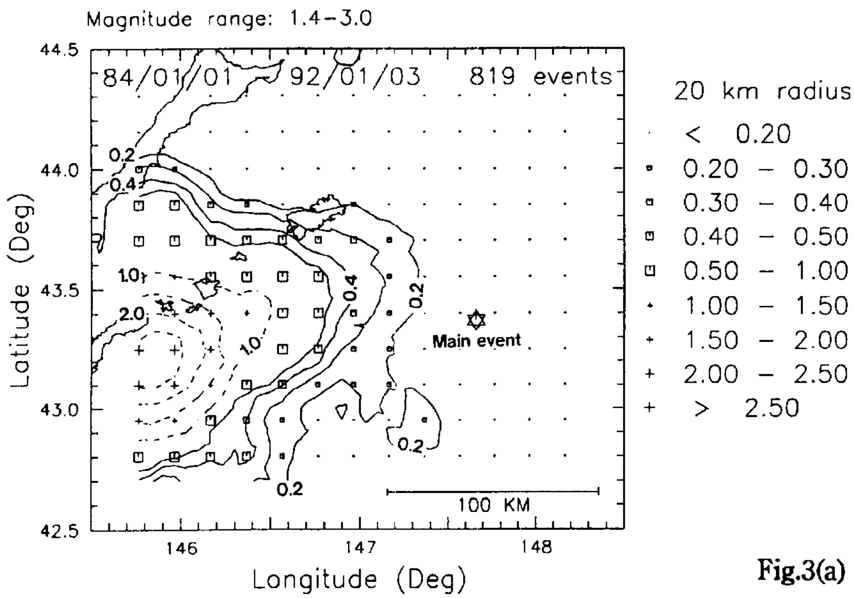

Fig.3(a)

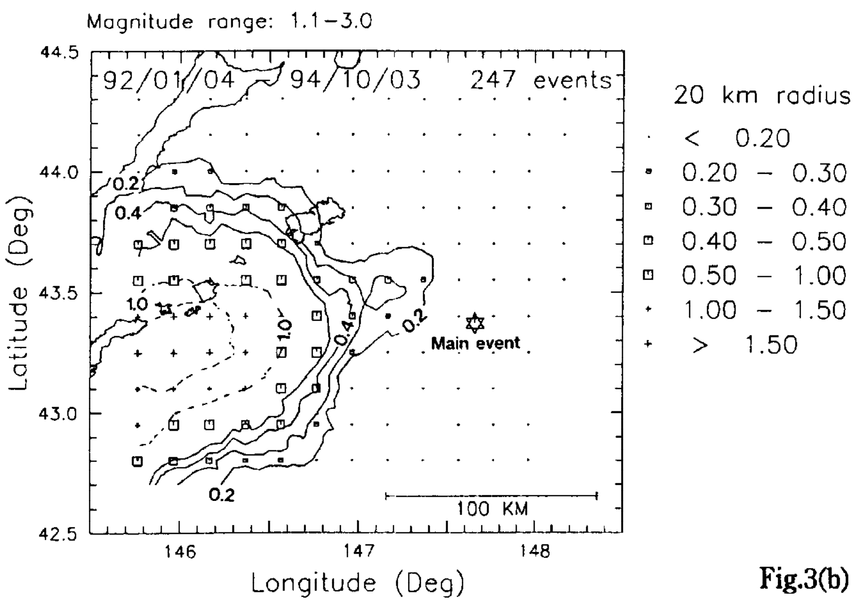

Fig.3(b)

Fig.3 Contour of the average number of earthquake per month, as in Figure 2 for m ≦ 3.0 for two time intervals as indicated. The thin-dashed contours have a minimum, maximum, and spacing in events/month of 1.0, 2.0, and 0.5, respectively in Figure 3(a), of 1.0, 1.5, and 0.5, respectively in Figure 3(b). Note that each contour enclose approximately the same region in all two time periods. The seismicity of the whole region does not change during the whole observation period, quite unlike the behavior of the larger m ≧ 3.5 events even in the neighborhood of the RCEP network.

the lower level seismicity not associated with the main shock, we have used two sets of contours and two different symbols: thin, dashed lines (accompanied by crosses as symbols) with large intervals in events/

month, to show the fine-structure of the seismicity in the high activity regions, and thicker lines (accompanied by squares as symbols) for the more interesting lower-level seismicity.

We produce contour plots for different time periods and magnitude ranges. A summary of our finding are shown in Figures 2 to 3. Figure 2 consists of two contour plots for m $\geqq$ 3.5 for time periods 1 January 1984 to 3 January 1992 and 4 January 1992 to 3 October 1994, henceforth called the "normal" pre-event period, the "quiescence" period, respectively. For 1984 to 1991 (Fig.2(a)), there is no clear pattern of seismicity. From 1992 until just before the main shock (Fig.2(b)), there is a general decrease in seismicity throughout the study region, which is most pronounced to the east of the main shock's epicenter.

Figure 3 shows the same two time span for magnitudes m $\leqq$ 3.0. Unlike the larger magnitudes, there is no applicable change in seismicity pattern between the two time periods. We have interpreted the results from our frequency magnitude study of events in the KMU region as showing that similarity and scaling did not hold for smaller magnitudes (Rydelek and Sacks, 1989; Taylor et al., 1990; Takanami et al.,1991).

DISCUSSION

The quiescence pattern described above 3 years for a magnitude 8 event is typical temporally of those reported for other events (e.g., Table 1 in Kanamori,1981). The pattern differs spatially in several important aspects from quiescence precursors described and discussed by most workers in the field (e.g. , Habermann , 1988 ; Reasenberg and Matthews,1988).
However, Taylor et al.(1990) described that their finding if the increase in activity at only the lower magnitudes in the focal region preceding the main shock and a qeiescence precursor at only the higher magnitudes is not unique.

Cao and Aki(1987) report several cases for which there appears to be a magnitude cut-off about which there is a quiescence precursors and below which there is often an increase in activity just before the main shock. They note that a cut-off magnitude of 3 was similar to the magnitude found in many studied for apossible breakdown in similarity of scaling laws (e.g., Aki, 1987; Dysart et al.,1988), and they propose a model involving a slip-weakening friction law to explain their observations.
Taylor et al.,1990) came to similar conclusions in their study of source parameters for events off Urakawa, Hokkaido. The earthquakes for which there was a possibly similar quiescence precursor to that we report for the Hokkaido-Toho-Oki earthquakes are the 1982 Urakawa-Oki earthquake (Taylor et al.,1991; Motoya,1984), the 1983 Japan Sea earthquake (Motoya,1984; Mogi,1985).
Stefan and Wyss(1994) also found that the hypothesis of precursory seismic quiescence is applicable in southern California by the different visualization technique.
The contouring procedure for portraing the changes in seismicity patterns with time is flexible yet easy to use and interpret. Given at least a few years of stable network operation, one can establish "normal" background levels for a region and can then produce routinely countours for comparison of different time slices and selected magnitude ranges.

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