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Precise aftershock distribution of the 2004 Mid-Niigata prefecture earthquake—Implication for a very weak region in the lower crust

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ABSTRACT

The 2004 Mid-Niigata prefecture Earthquake (Mjma 6.8) occurred in the region of large strain rates (>0.1 ppm/y contraction) in the intraplate region in Japan. The mainshock was followed by four major aftershocks with Mjma >= 6.0. The hypocenters of the mainshock and two large aftershocks that occurred in the central part of the aftershock region were located near the lower limit of the earthquake distribution, while hypocenters of the other two aftershocks near both ends, are located near its upper limit. Furthermore, the fault planes of the latter two aftershocks were confined within the upper half of the upper crust. Also, the lower limit of the aftershock distribution is deepest in the central part and becomes shallower toward the NNE and SSW ends. These data can be explained by the hypothesis that a localized stress concentration occurred near the bottom of the seismogenic region only in the central part. The stress concentration may be generated by the deformation in the very weak region of low strength in the lower crust beneath the central part of the aftershock region.

1. Introduction

Shallow intraplate earthquakes cause enormous damage; however, the process by which intraplate earthquakes are generated has been poorly understood and is still controversial, in contrast to interplate earthquakes. There are two end-member models of the process by which intraplate earthquakes are generated (Iio and Kobayashi, 2002). The first is called the regional stress model, in which broad-scale uniform regional stress generates intraplate earthquakes on pre-existing faults in the upper crust (e.g., Sykes, 1978; Hinze et al., 1988; Johnston and Kanter, 1990; Zoback, 1992). The second is the local stress model, in which local stress concentrations generate intraplate earthquakes (e.g., Campbell, 1978; Liu and Zoback, 1997; Stuart et al., 1997; Kenner and Segall, 2000). Iio and Kobayashi (2002) claims that the regional stress model cannot explain some of important problems concerning intraplate earthquakes, e.g., why and how is the stress accumulated on intraplate earthquake faults, despite the fact that stress at nearby plate boundaries is released quasi-periodically and is apparently not accumulated over the recurrence interval of interplate earthquakes? and why intraplate earthquakes do not trigger successive large earthquakes in adjacent regions? On the other hand, a local stress model, that assumes strength heterogeneities in the lower crust beneath the earthquake fault, can explain the above problems (Iio et al., 2002, 2004). The deformation in the weak zone in the lower crust can generate local stress concentrations in the upper crust and intraplate earthquakes can be generated at long recurrence intervals.

Recently, the heterogeneities in the lower crust beneath intraplate earthquake faults were associated with conductivity and seismic velocity anomalies, and it was found that strain rates detected by GPS were larger in the region above the heterogeneities than those in the surrounding region (Iio et al., 2002; Hasegawa et al., 2005). Iio et al. (2002) inferred that the lower crust beneath the large strain rate region (NKTZ, the Niigata–Kobe tectonic zone; Sagiya et al., 2000) is weakened by high water content and that the large strain rate is due to the lower strength of the lower crust beneath the region compared to the surrounding region.

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Table 1
List of the major earthquakes.

No.		Date	Origin time	Longitude	Latitude	Depth	Mjma	Error (km)
1	2004	October 23	17:56:00.005	138.8304	37.3052	11.120	6.8	0.254
2	2004	October 23	18:03:12.423	138.9621	37.3679	4.550	6.3	0.950
3	2004	October 23	18:11:55.529	138.7909	37.2745	2.667	6.0	4.556
4	2004	October 23	18:34:05.509	138.8974	37.3173	13.472	6.5	0.424
5	2004	October 27	10:40:49.979	139.0025	37.2989	13.873	6.1	0.238

Mjma is the magnitude determined by the Japan Meteorological Agency. Error is the standard error in hypocentral depth.

The 2004 Mid-Niigata prefecture (Chuetsu) Earthquake (Mjma 6.8) occurred on 23 October 2004 in the region of large strain rates in the intraplate region in Japan (NKTZ). The earthquake was followed by numerous aftershocks, including four aftershocks with Mjma (Japan Meteorological Agency Magnitude) greater than or equal to 6.0 (Kato et al., 2005; Aoki et al., 2005). The origin times and hypocenters of these five major events are listed in Table 1. The aftershock distribution was very complicated. Three or four major fault planes with almost parallel strikes are inferred from preliminary studies of the aftershock distribution using temporary seismic stations (Shibutani et al., 2005a; Sakai et al., 2005; Kato et al., 2005). One of the major differences among these studies is the hypocentral depth and the dip direction of the fault plane of the M6.0 aftershock (No. 3 in Table 1) that occurred at 18:11 on October 23, in the southern part of the aftershock region. It is important to determine the depth of the M6.0 fault, since this problem is closely related to the stress field in and around the aftershock region and the process by which this earthquake sequence was generated. We will precisely analyze the aftershock distribution, in particular, the depth of the M6.0 fault, and estimate the stress field and its heterogeneities, that may be the fundamental origin of the 2004 Mid-Niigata prefecture earthquake, in order to clarify the process by which intraplate earthquakes are generated.

2. Data, method and results

We located aftershock hypocenters based on 3D velocity models of P- and S-waves, which were obtained from a tomographic inversion method developed from SIMUL3M (Thurber, 1983). Initial values of hypocenters and station corrections were determined with a joint hypocenter determination method (Shibutani et al., 2005a). The distribution of 74 stations used in this study is shown in Fig. 1. DP.TDOM, DP.OJKW and DP.YMKS are temporary stations and the others are the permanent online stations operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), JMA, University of Tokyo and Tohoku University.

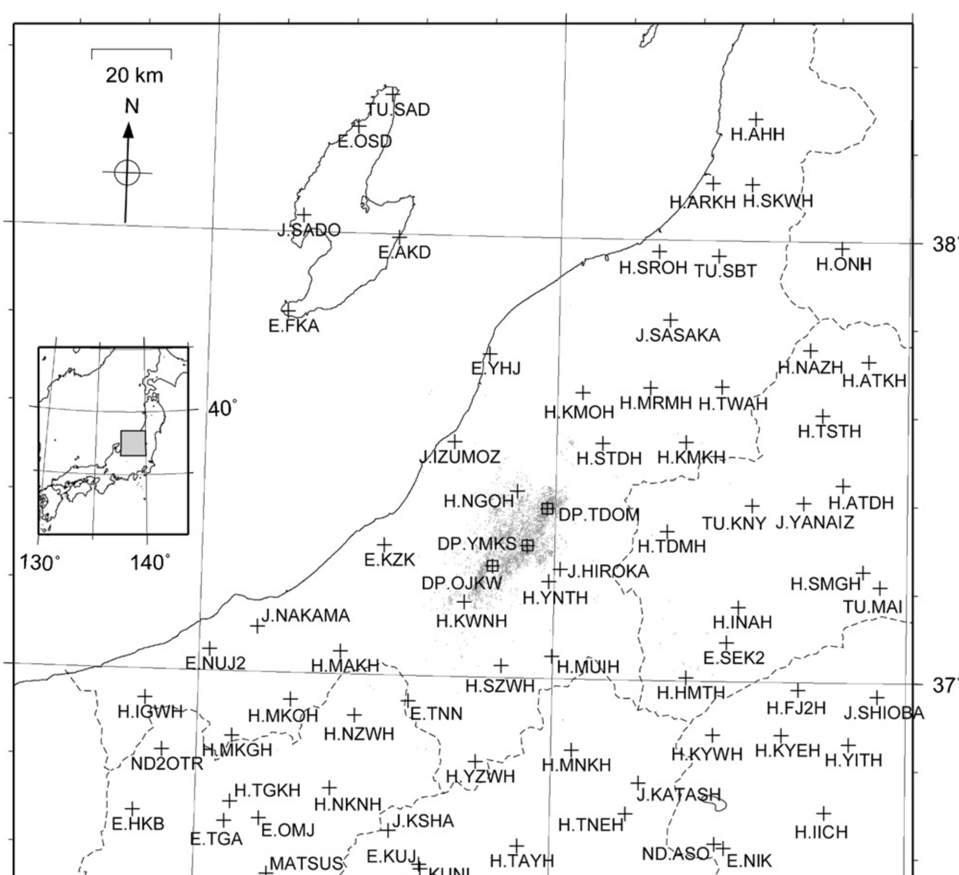

Fig. 1. Map showing the locations of the stations (crosses with square: temporary online, crosses: permanent online) used. Gray dots denote the aftershocks.