Aftershocks following the 2003 Tokachi-oki earthquake as evidence of conditionally stable sliding

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1. Introduction

A Mw 8 great thrust earthquake, the 2003 Tokachi-oki earthquake, hit off Tokachi, southern Hokkaido, on September 26, 2003 (JST). This area has repeatedly experienced similar thrust earthquakes due to the subduction of the Pacific Plate at Kurile Trench. Among such large earthquakes, the 2003 Tokachi-oki earthquake is the best observed one by highly dense seismogram and GPS networks, and provides us a good opprtunity to constrain frictional properties along the plate interface.

Ito et al., (2004, EPS) determined focal mechanisms and depths of large aftershocks using broadband seismographs and found that the majority of thrust aftershocks with mechanisms similar to the main shock (TH-type) occurred on the plate boundary. Yagi (2004, EPS) estimated the detailed rupture process of the main-shock and found that the rupture propagates mainly in the dip direction and TH-type aftershock activity is high in a zone of increased shear stress, northeast of the large stress-drop zone. Miyazaki et al., (2004, GRL) estimated the time and space distribution of after-slip using GPS data.

Compiling these results, we found that slip areas are partitioned on the plate boundary into distinct regions of coseismic slip and after-slip with TH-type aftershocks ocurring in the after-slip region. Distinct regions of coseismic slip and after-slip were also observed in other thrust earthquakes such as the 1994 Sanriku-haruka-oki and the 1996 Hyuga-nada earthquakes. The 2003 Tokachi-oki event is the first case we observed the TH-type aftershocks in the after-slip ragion. In this study, we estimated source processes of the large TH-type aftershocks and compared with the after-slip distribution. We also discussed the frictional properties of aftershock area.

2. Data and method

We examined three TH-type large aftershocks: Events A (Mw 5.9), B (Mw 6.4) and C (Mw 6.6) are located on the south, center, and east sides of the after-slip area, respectively. We selected 12 IRIS-DMC teleseismic stations, 2 F-net NIED broadband velocity stations and 2 K-net NIED accelerograph stations. We inferred the space and time distribution of fault slip using a multi-time window inversion, assuming the epicenter determined by JMA and the fault geometry used by Yagi (2004, EPS) (strile=250, dip=20). We also applied nonnegative least squares to constrain the rake angle between 85 and 175. Since the hypocentral depth is not well constrained by the local seismological network, we searched the minimum variance solution with respect to the hypocentral depth in the range of 10-40 km, keeping the fault plane and epicenter fixed.

3. Results

The inferred depths are 21, 30 and 33 km for events A, B and C, respectively, which are consistent with the depth of the plate boundary. The rupture of aftershock A is concentrated near the hypocenter with maximum slip of about 0.2 m; the slip area of aftershock B is expanded to southeast and northwest with maximum slip of about 0.25 m; the rupture of aftershock C, where activity of inter-seismic thrust earthquakes is high, unilaterally propagated to northeast with maximum slip of about 0.9m. It should be noted that the after-slip at B exceeded 0.4m, larger than the average slip of aftershock B (0.15m), and the other large TH-type aftershocks did not overlap with source area of aftershock B. On the other hand, Matsubara et al. (2004) found that the repeating earthquakes associated with the 2003 Tokachi-oki earthquake occurred in regions adjacent to the TH-type aftershock areas. All these results cannot be interpreted with a simple asperity model in which the stress is released by small amounts of unstable slidings. Instead these results imply that the TH-type aftershocks mostly occurred in a conditionally stable region where stable sliding is dominant under quasistatic loading but unstable sliding can occur associated with a sufficiently large slip velocity increase.