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Seismic waveform modeling for the source area of the 2004 Mid Niigata earthquake and the Implications for seismogenic conditions

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We investigated the seismic velocity structure in and around the source area of the 2004 Mid Niigata earthquake (Mw 6.6) which featured complicated heterogeneity by combining waveform modeling and travel time tomography inversion. This earthquake sequence involves in the rupture of at least three different faults (multiplanar fault system). On the footwall of the main shock that includes multiplanar faults, 3-D finite-difference waveform modeling using only a previously determined tomography model [Kato et al., JGR, 2006] was not sufficient to synthesize the observed waveforms between 0.05 and 0.2 Hz at most stations. Thus, we derived 3-D model 3DM-28 examining body-wave amplitudes, phases and travel times. Model 3DM-28 shows a clearer contrast between low- and high-velocities than the image seen in the original tomography models due to the higher velocity on the footwall. This increase in velocity, particularly in the seismogenic zone, is also accompanied by short wavelength low velocity anomalies revealed in the revised tomography image that are more localized in the vicinity of the multiplanar faults than the image in the original tomography model. Moreover, the low-velocity anomaly zone within a depth range of 15 to 20 km beneath the seismogenic zone (lower crust) appears to be associated with the short wavelength low velocity anomalies at shallower depths (upper crust). These characteristics may support the hypothesis of infiltration of pressurized fluids from the lower crust into the multiplanar fault system [Sibson et al., EPSL, 2007].

Subsequently, we considered possible seismogenic conditions from these results and the comparison with those for several other earthquake sequences in terms of the seismic properties of source parameters, aftershock activity and tectonics. The clear velocity contrasts between the low-velocity hanging wall and high-velocity footwall may be related to rupturing the hidden main fault in the tectonic strain concentration zone, such as the 2004 Mid Niigata earthquake (the 2007 Noto Hanto and the 2007 Off Mid Niigata earthquakes). The fault rupture process which seems to require high pore fluid pressure can explain the deviated seismic scaling relation from a cube law of seismic moment versus corner frequency in a source spectrum for these earthquake sequences [Tajima and Tajima, JGR, 2007; EPS, 2008], and the distribution of fluids is revealed as the low-velocity anomalies near and beneath the fault zones in our 3-D model [Tajima et al., GJI. 2009]. The fluids which locally existed near the fault zones also explain the large variation of the result of the seismic scaling relation for the small aftershocks (Mw 3.5 to 4.0). The interaction between the high-velocity brittle fault zones and the infiltrated fluids may play an important role in the rupture of other large faults and the production of a great number of aftershocks in the 2004 Mid Niigata earthquake sequence. Therefore, we suggest that the clear velocity contrasts between the hanging wall and footwall, and the upper crust and lower crust, including the effects of fluids, all seem to be essential seismogenic conditions in the complicated crustal earthquake sequence such as the 2004 Mid Niigata earthquake sequence, and the characteristics also seem to be reflected in the seismic scaling relations.