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Aftershock activity of the 2008 Iwate-Miyagi inland earthquake suppressed by stress shadow of the 2011 Tohoku earthquake

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The 2011 Tohoku-oki M9 earthquake has increased seismicity rates in many areas in eastern Japan. Several papers already sought the triggering mechanism to static stress change (Toda et al., GRL, 2011), dynamic stress change (Miyazawa et al., GRL, 2011) and pore fluid pressure change (Terakawa et al., EPSL, 2013). In contrast, areas where seismicity rate evidently dropped are restricted to the vicinity of the 2011 rupture zone (Kato & Igarashi, GRL, 2012), the 2004 Chuetsu aftershock zone (Hirose & Toda, SSJ fall meeting, 2011) and the 2008 Iwate-Miyagi inland earthquake aftershock zone (Suzuki & Toda, AGU fall meeting, 2013). Suzuki and Toda (2013) claim that the cause of seismic quiescence is Coulomb failure stress (CFF) decrease due to the 2011 event. However, a small quantity of focal mechanisms prevents them to confirm the mechanism.

In this study, we determine 4106 newly focal mechanisms in the area and develop a model to explain spatio-temporal seismic evolution. To estimate the focal mechanisms, we employ the method of Hardeback & Shearer (BSSA, 2002) using first motion of P-wave, provided by the campaign data by the Group for the Aftershock Observations of the 2008 Iwate-Miyagi inland Earthquake and Japan Nuclear Energy Safety Organization (JNES) in addition to the stationary data from Hi-net and F-net by NIED. Besides, we use F-net moment tensor solutions (VR?80%) and JMA focal mechanisms together with our estimates. Most of the focal mechanisms are strike-slip or thrust fault type and the distribution of ratio of strike-slip type to thrust type is spatially heterogeneous. We find several distinctive seismic clusters from all the distribution. Seismicity in two clusters in southern rupture zone of the 2008 event has been clearly decreased by the 2011 event. We calculate △CFF on all nodal planes as a proxy for background faults using a Tohoku-oki coseismic slip model given by Iinuma et al. (JGR, 2012) in an elastic half-space of Okada (BSSA, 1992). Apparent friction coefficient, μ' , is assumed to be 0.0, 0.4 or 0.8. In the case of μ' =0.0, 80% of △CFF resolved on all nodal planes are negative and over 50% △CFF are negative in the case of μ' =0.8. In the distinctive clusters mentioned above, ratios of the negative △CFF far exceed above overall average.

Seismic response to △CFF is formulated by Dieterich (JGR, 1994) based on the rate-and state-dependent friction law. The physics-based model can reproduce the empirical Omori's aftershock decay after a stress step controlled by several parameters. In this study, we estimate reference seismic rate from an average number of earthquakes from 2000 to the 2008 mainshock, △CFF associated with the 2008 mainshock, stressing rate, product of constitutive parameter and normal stress on a fault plane ($A\sigma$) estimated from the aftershocks occurred until the Tohoku-oki earthquake. Using these parameters, we calculate seismic time series from all the calculated △CFF by the Tohoku-oki earthquake, and then compare the observation with the average of all time-series curves. As a result, the models increase seismicity rate at the Tohoku-oki earthquake, which is inconsistent with the observation. We seek that reasons for mismatch between our model and observation to (i) the paucity of aftershock hypocenter data because of detectability decrease immediately after the Tohoku-oki earthquake, (ii) change in stressing rate due to the post-seismic deformation of the Tohoku-oki earthquake, (iii) reduction of friction coefficient due to fluid injection and/or pore pressure change on fault planes.

Acknowledgments. We are grateful to JMA and NIED for hypocenter list and fault plane solutions. We also thank the regional campaign data given by the Group for the Aftershock Observations of the 2008 Iwate-Miyagi inland Earthquake and JNES.

Keywords: induced earthquake, static Coulomb failure stress change, rate-and state-dependent friction law, seismic quiescence

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Improvement of gas medium triaxial apparatus derived from thermal fluid analysis

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A huge amount of effort has used to be required for trial productions during the development of experimental apparatus. Since such trial productions generally consume vast time period and cost, the reduction of them is now a significant issue. Numerical modeling such as the finite element simulation (FE) is widely used to reduce them in various engineering fields.

Gas medium triaxial apparatus is widely used to determine the mechanical properties of rocks precisely at higher temperature. However, there has been a limitation for the use at the higher temperature in Japan due to the thermal design. In this presentation we plan to improve the gas-medium triaxial appratus derived from thermal fluid analysis based on the finite element simulation.

Here, the governing equations for thermal fluid analysis consist of the heat conduction equation, the Navier-Stokes equation and the equation of state. By solving those equations simultaneously, we obtain important physical quantities such as temperature distribution, fluid velocity field, delay of heating, etc. The knowledge derived from the computer simulations are: (1) The argon gas flow hardly has any relation with the temperature distribution on solid materials. (2) The temperatures of adiabatic materials placed near the heat sources are below the maximum operating temperature. (3)A large thermal gradient is observed close to the plastic O-ring.

Based on above results, we have attained valuable improvement policies such as replacement of meterials, improvement of radiation factor on the copper jig, etc.

Keywords: heat, fluid, Navier-Stokes, equation of state, gas medium triaxial apparatus

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The crustal structure beneath northern Mino region, central Japan revealed by seismic reflection survey

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The Nobi earthquake, the largest inland earthquake in Japan, occurred in 1891 in northern Mino district, central Japan. In that region, most active faults run nearly parallel to the NW-SE trending hinge of megakink structure of the Mino belt (Kano et al., 1990). It is remarkable that the upper surface of the subducting Philippine Sea Plate (PSP) also shows a NW-SE trending broad anticlinal form whose axial zone is deeply situated almost below the hinge of the magakink. However we don't have sufficient information about seismic structure of whole crust and the uppermost mantle beneath this region to discuss influence of subducting plate on surface deformation.

To elucidate the seismic structure, a seismic reflection survey was carried out in October in 2009 (Komada et al.,2010). The survey line intersected at high angle with Neodani faults zone. We applied the seismic reflection method to the shot records of this survey and got seismic profiles of whole crust and the uppermost mantle.

We found reflectors having 2 s duration around 10 s two way travel time (TWT) in the seismic profiles. These waves occurred at TWT 9 - 11 s in the southwestern part of the study area, and at TWT 10 - 12 sec in the northeastern part. Applying depth conversion, the reflectors are located in the depth of 28 - 37km in the southwestern part, and of 32 - 39km in the northeastern part. We can clearly see that the depth of the reflection waves in the southwestern side of the Neodani fault zone are shallower than that in the northeastern side. Further the depth varies just beneath the Neodani fault zone. These feature correspond with the result of velocity analysis in the study area (Emoto et al., 2012).

Those reflection waves are interpreted as a lower crustal lamination by comparing with the result of previous seismic profiles. The geometry of laminated lower crust is consistent with the trend of the displacement on Nodani Fault Zone of Nobi earthquake. The fact might show that the difference of the reflectors depths between the southwestern and the northeastern side is caused by fault displacement and it might reach the whole crust. In southwestern part of study area, the depth of top boundary of the Philippine Sea plate (PSP) was estimated from travel time tomography in the previous studies. Its depth is equivalent in the lower limit of the lower crustal lamination. Then it might show that the crust of the land plate contacts on the subducting PHP beneath the northern Mino district.

Keywords: lower crust, Neodani fault, reflection seismic survey, Philippine Sea Plate, northern Mino region

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Temporary observation of micro earthquakes in the northern Ibaraki prefecture by using commercially-supplied IC recorder

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In case of estimate focal mechanism solutions by using P-wave first-motion polarity data, a dense seismic observation network is required. In this study we propose a new seismic observation system to record a P-wave first-motion polarity. The system consists of a seismometer with a vertical component that price is approximately ten thousand yen and a commercially-supplied IC recorder that price is approximately ten thousand yen. According to the specification of the IC recorder, the recordable frequency band is from 60 to 3400 Hz. We compare frequency characteristic of waveforms recorded in stations of National Research Institute for Earth Science and disaster Prevention (NIED Hi-net) and those recorded by using IC recorder. As a result we find that the IC recorder is able to record seismic waves that frequency band is from about 20 to 3400 Hz.

In this study, we conducted a temporary observation of micro-earthquakes for one month from August to September 2012 in the northern Ibaraki prefecture where many normal-faulting type events occur, and we addressed the effectiveness of the seismic observation system. The 29 seismic stations were deployed along a road so that it allows a deployment of many stations for a short time. After collecting the temporary stations, based on the P-wave first motion polarity, we estimated the focal-mechanisms by using HASH program (Hardebeck and Shearer, 2002). As a result, we obtain the 87 focal-mechanisms for micro-earthquakes occurred in the study area.

To test the accuracy of the focal mechanisms obtained in this study, we compared those with focal-mechanisms determined by Earthquake Research Institute, The University of Tokyo (ERI) temporary stations. We compared focal-mechanisms determined by ERI and Hi-net stations and focal-mechanisms determined by using IC recorder and Hi-net stations. We compare P axis and T axis for focal-mechanisms determined by ERI and Hi-net stations and determined by using IC recorder and Hi-net stations. As a result, nothing is difference of accuracy about focal-mechanisms between determined by ERI and Hi-net stations and determined by using IC recorder and Hi-net stations, because of P axis T axis has almost same distribution on the focal sphere. We conclude that focal mechanisms determined by using IC recorder stations has almost same accuracy as those determined by a traditional three component seismometer.

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Modeling the viscoelastic deformation of the NE Japan arc after the 2011 Tohoku-oki earthquake

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The rheological structure of the Northeastern Japan arc crust and the upper mantle is heterogeneous along and transverse to the arc. Shibazaki et al. (2014) developed a model of the stress state of the Northeastern Japan island-arc crust using a finite element method with viscoelasticity and elastoplasticity. They reproduced several elongated low-stress regions transverse to the arc with viscous deformation that corresponds to hot fingers (high-temperature regions in the mantle wedge). The viscous relaxation process after the 2011 Tohoku-oki earthquake could be affected by the existence of low-viscosity regions caused by hot fingers. A three-dimensional (3D) finite element model was developed to investigate the viscoelastic deformation processes with heterogeneous viscosity distribution after the 2011 Tohoku-oki earthquake. The model considers the realistic crustal and mantle structures, viscoelasticity (Maxwell or Burgurs rheology), and coseismic fault slip distribution obtained by Iinuma et al. (2012). For simplicity, only the elastic crust and viscoelastic mantle structure were considered. The westward movement near the trench and eastward movement in the inland region due to viscoelastic relaxation were reproduced, which are consistent with the observations. We also consider the local low viscosity region in the Northeastern Japan arc crust. In this case, extensional viscous strain concentrates on this region. We report the numerical results that take into account the realistic 3D heterogeneous viscosity distribution in the crust and the upper mantle beneath the Northeastern Japan island arc.

Keywords: 2011Tohoku-oki earthquake, NE Japan arc, Viscoelastic deformation