Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG66-01 Room:414 Time:April 30 09:00-09:15

Development of heterogeneous rheological model of the Tohoku Island arc-trench system

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Subduction zone earthquake cycles can be characterized by various deformation processes taking place around the plate boundary and surrounding area. For example, after slip, viscoelastic relaxation and locking of the plate boundary are three primary processes among them. In order to illuminate the recovery of plate coupling after the Mw 9.0 Tohoku-Oki earthquake and strain budgets of island arc during cycles, the detailed viscoelastic structure of the Tohoku region is developed using seismologically determined subsurface structures and densely measured geothermal gradient data. The model is oriented perpendicular to the Japan Trench and also transects an area of large coseismic slip of the 2011 Tohoku Oki earthquake. Petrological model proposed by the laboratory measurement of seismic velocity of various rocks [Nishimoto et al., 2005] was utilized to infer rheologically major minerals from seismic velocity structures. We used geothermal gradient data from the inland Hi-net borehole [Matsumoto, 2007], as well as geothermal gradient data compiled from around Japan [Tanaka et al., 2004]. The strain-rate-dependent, steady state effective viscosity was calculated using constitutive laws of various rocks under the assumption of homogeneous geologic shortening rate [Sato, 1989]. The calculated viscosity structures show lateral viscosity gradients both parallel and normal to the trench axis. Moreover, the minimum viscosities are predicted to be 10^{19} Pa s in the mantle wedge and 10^{20} Pa s in the oceanic mantle. The values are consistent with previous estimates obtained by postseismic deformation analysis of subduction zone earthquakes with similar magnitudes (Mw ~9). However those minimum values only appear in depths of 30-100 km in the upper mantle and the viscosity increases further with depths because of the pressure hardening effect. Taking the high values of viscosities in shallower part of the lithosphere, the thickness of high viscous layers found to have lateral variations implying the heterogeneous elastic layer thickness. Model viscosity structures of the Tohoku region utilizing realistic temperature and rheological properties of rocks can be used to evaluate the effect of rheological heterogeneity in the postseismic deformation field of the Tohoku-Oki earthquake observed by dense network of geodetic observations. In the presentation, we will mention the detailed information on the choice of the flaw law parameters, and physical and ambient conditions for NE Japan to calculate the viscosity structures. We also show how these heterogeneities affect the crustal deformation of the NE Japan during subduction zone earthquake cycles.

Keywords: rhology, Tohoku, viscoelastic relaxation, earthquake cycle, Tohoku oki earthquake

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Detailed seismic attenuation structures beneath the Hokkaido corner, northern Japan (3)

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1. Introduction

In the Hokkaido corner, the Kuril fore-arc sliver collides with the northeastern Japan arc. Using travel-time data compiled from the nationwide Kiban seismic network and a dense temporary seismic network [Katsumata et al, 2002], Kita et al. [2012] determined high-resolution 3D seismic velocity structure beneath this area for deeper understanding of the collision process of the two fore-arcs. In this study, we merged waveform data from the Kiban-network and from the temporary network, and estimated the seismic attenuation structure to understand seismotectonics and collision process beneath Hokkaido.

2. Data and method

We estimated corner frequency for each earthquake by the spectral ratio method of coda waves [e.g. Mayeda et al., 2007]. Then, we simultaneously determined values of $t*$and the amplitude level at low frequencies from the observed spectra after correcting for the source spectrum. Seismic attenuation (Q-1 value) structure was obtained, inverting $t*$values and employing the 3-D ray-tracing technique of Zhao et al. [1992]. The study region covers an area of 41-45N, 140.5-146E, and a depth range of 0-300 km. We obtained 154,293 $t*$at 316 stations from 6,196 events (Mj$>$2.0) that occurred during the period from Aug. 1999 to Dec. 2012. Horizontal and vertical grid nodes were set with spacing of 0.1-0.3 degrees and 10-30 km, respectively.

3. Results

The calculated stress drops are distributed from 0.1 to 100 MPa. Stress drops of intraslab earthquakes increase with focal depth. The values of stress drops of events in the slab mantle tend to be larger than those in the slab crust at depths of 80 to 170 km, which might contribute to understanding of the physical nature of intraslab earthquakes.

Seismic attenuation structure is imaged for the region above the subducting Pacific slab at depths down to ~80 km. For the forearc side of the eastern and western parts of Hokkaido, high-Qp zones are generally imaged at depths of 10 to 80 km in both the crust and mantle wedge above the Pacific slab. In contrast, low-Qp zones are clearly imaged in the mantle wedge of the backarcside.They are distributed in deeper parts and reach the Moho beneath the volcanic front. Locations of these low-Qp zones correspond to the low-Vp and low-Vs zones imaged by Zhao et al. [2012]. These suggest that the upper head of the mantle-wedge upwelling flow is detected beneath Hokkaido also by our seismic attenuation imaging.

In the Hokkaido corner, to the west of the Hidaka main thrust a broad low-Qp zone is imaged at depths of 0?60 km. Location of this broad low-Qp zone almost corresponds to that of the low-V zone in the collision zone found by Kita et al. [2012]. Fault planes of the 1970 M6.7 and 1982 M7.1 earthquakes are located at the edges of a broad low-Qp zone, being in contact with a high-Qp zone at 10 to 35 km. These results suggest that the occurrence of these anomalously deep and large inland earthquakes is related to the presence of hydrous minerals or fluids.

The subducting oceanic crust beneath the Hidaka region is imaged as a low-Q zone whose location corresponds to the low-Vp and low-Vs zone of Kita et al. [2012], suggesting the existence of hydrated materials at the top of the slab. Just above the slab surface, moderately low-Q zones are imaged at depths of 90 to 100 km beneath eastern and southern Hokkaido and at depths of 110 to 130 km beneath the corner, which are located at depths deeper than the upper plane seismic belt. These observations suggest the existence of the hydrated mantle wedge by the aqueous fluids supplied from the oceanic crust right below.

Keywords: Seismic attenuation structure, Seismotectonics, arc-arc collision process, Stress drops of intraslab earthquakes

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SCG66-03 Room:414 Time:April 30 09:30-09:45

Crustal deformation in the Mid-Niigata area and its implication for strain concentration

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The Mid-Niigata area is located within the concentrated strain belt along the eastern margin of the Japan Sea. This area suffered from two large earthquakes, the 2004 Chuetsu and the 2007 Chuetsu-oki earthquakes. Based on GPS velocity data calculated from daily coordinate time series of GEONET, we identified significant time dependence of the interseismic crustal deformation patterns before, between, and after these two earthquakes. Modeling results of the deformation pattern changes are summarized as follows. 1) Contraction before 2004 occurred between the source regions of the two earthquakes and it was attributed to aseismic faulting across almost the whole elastic layer, implying that the observed strain was largely inelastic. This interpretation is also supported from a fact that the historical seismic energy release in this area is much smaller than that expected from geodetic strain accumulation. 2) After two earthquakes, aseismic faulting seems to have continued without explicit time decay. The aseismic faulting is estimated close the source fault of the main shocks, implying that postseismic strength recovery did not occur on the main shock fault or a nearby parallel fault was activated to accommodate regional contraction. This is consistent with an idea that the upper crust in this area is segmented to smaller blocks and the mechanical behavior is very sensitive to external stress changes.

Keywords: Strain concentration, Niigata-Kobe Tectonic Zone, 2004 Chuetsu earthquake, 2007 Chuetsu-oki earthquake, aseismic faulting, inelastic deformation

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SCG66-04 Room:414 Time:April 30 09:45-10:00

Tectonic stress fields in subduction zones governed by frictional strength of plate interfaces

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Tectonic crustal motion in plate convergence zones varies from mountain building (e.g., Himalaya) to back-arc spreading (e.g., Mariana) [1, 2, 3]. Such difference in tectonic crustal motion reflects the diversity of tectonic stress fields. So our question is what causes the diversity of tectonic stress fields in plate convergence zones. Recently, from a theoretical study [4], we revealed that the tectonic stress field consists of basically two different sorts of stress fields; one of which is a horizontally compressional stress field due to frictional resistance at plate interfaces, and another is a horizontally tensile stress field due to steady plate subduction. On a geological timescale, the former can be regarded as constant in time, but the latter increases with time. So, if the earth's crust were infinitely strong, tectonic stress fields in plate convergence zones would become tensile in time everywhere. Actually, the earth's crust includes a number of defects with low strength, over which inelastic deformation (brittle fracture and/or plastic flow) occurs so as to release the tectonic stress caused by mechanical interaction at plate interfaces. From these considerations, we may conclude as follows. When the plate interface is very weak in comparison with the earth's crust, a horizontally tensile stress field becomes dominant, which causes back-arc spreading as in the case of Mariana. When the plate interface is very strong, a horizontal compressional stress field becomes dominant, which causes mountain building as in the case of Himalaya. Tectonic stress fields in most subduction zones, where the strength of plate interfaces are comparable to that of the earth's crust, are between these two extreme cases.

References

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Keywords: subduction zone, tectonic stress field, plate interface, frictional strength, mountain building, back-arc spreading

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Sequential inversion of GPS time series data to estimate spatiotemporal change in interplate coupling

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To estimate steady increase rates of slip deficits at plate interfaces, first, we obtain linear trends of the time series of GPS daily coordinate data by removing seasonal variations and coseismic and postseismic changes due to episodic events. Then, we invert the linear trends (surface displacement rates at GPS stations) into steady slip-deficit rate distribution on a plate interface with completely relaxed slip-response functions for an elastic-viscoelastic layered half-space model under gravity (Noda et al., 2013, GJI). Noda et al. (SSJ 2012 Annual Meeting) demonstrated that this method is applicable to GPS time series data in northeast Japan for the interseismic period (March 1997-February 2008) before the 2008 Ibaraki-oki (Mw6.8) and Fukushima-oki (Mw6.9) earthquakes. After these events, the trends of GPS time series data gradually change with time (Suito et al., 2011, EPS), indicating spatiotemporal change in interplate coupling preceding the 2011 Tohoku-oki mega-thrust earthquake.

The change in slip-deficit rate distribution disturbs a steady stress state in the asthenosphere, and so we need to use the viscoelastic transient slip-response functions for the analysis of GPS time series data after the 2008 events (Noda et al., 2013, GJI). An exact treatment of the viscoelastic inverse problem to estimate cyclic slip processes at a plate interface has been given by Fukahata et al. (2004, GJI), but it is not applicable to the present problem because the change in slip-deficit rate distribution is not a cyclic but transient process. So, we propose a simple inversion technique, called sequential inversion of GPS time series data, to estimate spatiotemporal changes in slip-deficit rates at plate interfaces. A similar sequential inversion technique has been used by Lubis et al. (2013, GJI) for the analysis of afterslip distribution following the 2007 southern Sumatra earthquake (Mw8.5) on the assumption that the asthenosphere has been in a steady stress state until the 2007 event.

In the present study, we estimate the spatiotemporal change in interplate coupling by applying the sequential inversion technique to GPS time series data for March 2008-February 2011, and reveal the slip history at the North American-Pacific plate interface off Tohoku during the 14 years before the 2011 Tohoku-oki mega-thrust earthquake.

Keywords: GPS time series data, sequential inversion, viscoelastic transient response, change in interplate coupling, the 2011 Tohoku-oki earthquake

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Middle Miocene swift migration of the TTT triple junction and rapid crustal growth in SW Japan

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We review recent progress in geological and geophysical investigation in SW Japan, the Nankai Trough and the Philippine Sea Plate (PSP), and propose a comprehensive hypothesis for the Miocene tectonics of the Nankai Trough. New interpretations are as follows: Near-trench magmatism in the outer zone of SW Japan might have various reasons. The possibility of an arc-arc collision in particular should be examined, in addition to the previous model of an oceanic ridge and hot PSP subduction. The indentation structure at Capes Ashizuri, Muroto in Shikoku, and Shiono on the Kii Peninsula may be explained by the collision of the active arc or topographic peaks such as seamounts, contrary to the previous "kink-folding" model due to recent E-W compression. This inference is drawn from comparison between the many modern examples of seamount collision and sandbox analogue experiments. Crustal components of SW Japan might consist mainly of igneous plutonic rocks, in contrast to the previous inference of Cretaceous to Tertiary accretionary complexes. This is especially the case in the outer zone to the north of Capes Ashizuri, Muroto and Shiono. This is inferred from geophysical observation of gravity anomalies, velocity and resistivity, together with geological estimations of caldera age and the size of its root pluton. Episodic crustal growth due to intrusion of igneous rock and subduction of the PSP may have stopped after ~11 Ma and restarted at ~7-8 Ma. New accretionary prism was again developed after ~6 Ma. This inference is suggested by recently conducted ocean drilling program.