SCG65-01 Room:201A Time:May 19 11:00-11:15

Relation between stress field around active fault and fault activity

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In order to evaluate potential of fault activity, it is important to estimate effect of stress acting on active faults. We analyzed 'slip-tendency' that defined as the ratio of shear stress to normal stress acting on the surface of fault plane (Morris et al., 1996). The stress field is obtained based on the focal mechanisms data in intra-plate region, central Japan, estimated by Yukutake et al., (2012). Applying the stress inversion method (Hardebeck and Michael, 2006) to the focal mechanisms data, we estimated the stress state around active faults. Parameters about the position, strike and dip angle of active faults are taken from 'Active fault database of Japan' by The National Institute of Advanced Industrial Science and Technology (http://riodb02.ibase.aist.go.jp/activefault/). We found that most of active faults with large average slip rate (more than or equal to 1m/year) are likely to have large slip-tendency.

Keywords: Stress field, Active fault, Slip tendency

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SCG65-02 Room:201A Time:May 19 11:15-11:30

Determination of effective friction coefficient by optimizing slip tendencies on fault plane orientation distribution

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Friction coefficient (mu) on fault is one of the most crucial parameters to evaluate the risk of faulting and to modeling tectonic phenomena. It is difficult to estimate the coefficient especially of underground faults and of ancient geological faults. This paper proposes a stochastic method to determine the effective friction coefficient from a distribution of fault surface orientations.

The geological faults and observed seismicities are definite proofs of (ancient) slippage. They are expected to provide information on frictional properties in the earth's crust. Stress tensor inversion techniques applied to such meso-scale faults and seismic focal mechanisms usually determine a reduced stress tensor composed of three principal stress orientations and a stress ratio. Angelier (1989) tried to determine all six independent components of stress tensor including magnitudes of principal stresses, assuming that the normal stress (Sn) and shear stress (Ss) on observed fault surfaces satisfies Ss/Sn >= mu. In his analysis, the friction coefficient can be determined graphically on Mohr's diagram, although there remains an ambiguity to recognize the straight line Ss/Sn = mu that bounds the distribution of points showing stresses on faults. The purpose of this study is to remove this ambiguity during the determination of friction coefficient.

The new method proposed by this study utilizes the slip tendency (Morris et al., 1996), which was introduced to quantify the tendencies of reactivations of faults in fractured rock masses. This parameter is strongly related to the friction coefficient since it is defined as the simple ratio between normal and shear stresses (Ss/Sn) on a fault surface. Slip tendency calculation has been applied to both geological faults and present seismicities (e.g., Collettini and Trippetta, 2007; McFarland et al., 2012), and it was confirmed that the natural frequency of fault orientations appears to obey the slip tendency (Lisle and Srivastava, 2004). This study presumes that the frequency of fault orientations is a monotonously-decreasing function of the reciprocal of slip tendency (Sn/Ss). Then we can compose an inversion method for fitting the shape of the function to observed distribution of fault orientations. If the optimized frequency distribution function has a sudden decrease to zero at a certain value of slip tendency, the value can be interpreted as the desired friction coefficient. Note that what can be determined is an effective friction coefficient under the influence of pore fluid pressure.

The new method was applied to 122 meso-scale fault-slip data gathered from the Pleistocene Kazusa Group, eastern Boso peninsula. N-S striking normal faults dominate the data set, and a single-phase E-W tensional stress was detected by a stress inversion analysis. As the result, the internal friction coefficient was determined to be 0.45 +0.34/-0.09. The precision estimated by bootstrap analysis was large because the shape of the optimized frequency distribution function was unfortunately convex. The friction coefficient around 0.45 is slightly small but appears to be reasonable for a young sedimentary rock.

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Keywords: stress tensor inversion, effective friction coefficient, slip tendency, orientation distribution, fault-slip analysis

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SCG65-03 Room:201A Time:May 19 11:30-11:45

Crustal stress field formed by plate convergence and topography in northeastern Japan

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We estimated the crustal stress field in northeastern Japan prior to the 2011 Mw9.0 Tohoku-Oki earthquake based on earthquake focal mechanisms determined using seismograms from temporary and permanent seismic networks deployed in this area. Results show that the arc and back-arc are characterized by spatially uniform margin normal compression. However, the fore-arc has different stress orientations. The Kitakami and Abukuma mountain ranges in the north and south have s1 axis oriented nearly N-S and vertical, respectively, and the region in between without mountain range has a similar stress field to the arc and back-arc. This indicates that the margin normal compression in the arc and back-arc is not caused mainly by the coupling with the Pacific plate but perhaps by the convergence of the Eurasia plate from the back-arc side. Anomalous stress fields in the mountain ranges of the fore-arc are probably due to gravitational force.

Spatially homogeneous margin normal compression is observed throughout the arc and back-arc as already mentioned, but the stress field even in those regions might also be influenced by the topography. Using the distribution of the generalized stress ratio (Simpson, 1997), we found a clear spatial correlation between strike-slip fault stress regime (i.e. higher sv) and high mountain ranges in those regions, which again suggests that the prevailing stress field has been influenced by topographic loading, though the s1 orientation is constant.

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SCG65-04 Room:201A Time:May 19 11:45-12:00

Temporal stress change around the Iwaki-city in northeast Japan before the 2011 Tohoku earthquake

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We present the temporal heterogeneities of the crustal stress before the 2011 Tohoku earthquake around the Iwaki-city using the small magnitude earthquakes. Otsubo et al. (2008; Tectonophysics, 457, 150-160) proposed a stress tensor inversion method to separate stresses from earthquake focal mechanism data from spatially and temporary varying state of stress. The method is applied to focal mechanisms of the earthquakes collected by Imanishi et al. (2012; Geophys. Res. Lett., 39, L09306).

The inversion method revealed two normal-faulting stress states, corresponding to two stress periods and the transition between the two stress periods corresponds to the period between 2005 and 2008. In the stress period I from 2003 to 2005, a WNW-ESE trending tri-axial extensional stress is dominant. The stress ratio increases from the stress periods I (Phi = 0.5) to II (Phi = 0.8) in this area. The temporal changes of S3-axis orientation and stress ratio of stress state had induced by the event that occurred during 2005 and 2008. We interpret that the changes of the stress period from I to II are induced by the extension during the post-seismic deformation of the M 7-class earthquake. We estimate the magnitude of the change of differential stress from the Stress B to A. The differential stress of the Stress A is estimated at ~3 times as large as at the differential stress of the Stress B under these assumptions.

We revealed that the pre-shock normal-faulting stress regime had been built up by 2003, furthermore the differential stress of the pre-shock normal-faulting stress was increased by the post-seismic deformations of the M 7-class earthquake before the 2011 Tohoku earthquake. The increase of the differential stress has contributed to the stress accumulation that can be sufficient to cause an inland earthquake by amount of stress change of the 2011 Tohoku earthquake around the Iwaki-city.

A part of this research project has been conducted as the regulatory supporting research funded by the Secretariat of Nuclear Regulation Authority (Secretariat of NRA), Japan.

Keywords: multiple inverse method, focal mechanism, large trench type earthquake, post-seismic deformations, active fault, 2011 Iwaki earthquake

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SCG65-05 Room:201A Time:May 19 12:00-12:15

Stress drops of induced earthquakes associated with the 2011 Tohoku-oki earthquake

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After the occurrence of the 2011 Mw 9.0 Off the Pacific Coast of Tohoku Earthquake (Tohoku-oki earthquake), induced earthquakes are actively occurring at several inland areas, including Fukushima Hamadori region and the middle part of the Akita prefecture. Focal mechanisms of these induced earthquakes are inconsistent with the present-day stress field in overall northeast Japan that is characterized by a reverse-faulting regime with E-W compression. One possible mechanism is that the stress field in those areas abruptly changed from horizontal compression to extension because trench-normal compressive stress within the overlying plate was reduced after the Tohoku-oki earthquake (Kato et al., 2011; Yoshida et al., 2011). If so, the differential stress magnitudes in those areas before the Tohoku-oki earthquake should be smaller than the static stress changes associated with the Tohoku-oki earthquake (1 MPa or less). Moreover, it is expected that stress drops of these induced earthquakes is less than 1 MPa. In this study, we determined stress drops of these induced earthquakes by using the Multi-Window Spectral Ratio method (Imanishi & Ellsworth, 2006). The estimated stress drop values are approximately 10 MPa, which is inconsistent with the hypothesis of a drastic change in stress state. The present result rather favors the conclusion of Imanishi et al. (2012) that the Tohoku-oki earthquake could trigger those earthquakes in a limited area combined with a locally formed pre-shock stress regime that is different from a reverse-faulting one with E-W compression. Terakawa et al. (2013) indicate that the increase in fault-confined fluid pressure would have played a critical rule in the occurrence of these induced earthquakes. This mechanism and the combination with the locally formed pre-shock stress heterogeneity are also enabled if the fault strength was still in excess of approximately 10 MPa (the stress drops of induced earthquakes).

Acknowledgements: The seismograph stations used in this study include permanent stations operated by NIED (Hi-net).

Keywords: induced earthquake, the 2011 Mw 9.0 Off the Pacific Coast of Tohoku Earthquake, stress drop, stress field, MWSR method

SCG65-P01 Room:Convention Hall Time:May 19 18:15-19:30

Focal mechanisms around the northwest margin of the Kanto Plain (Kanto-heiya-hokuseien) fault and Tachikawa fault zones

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We investigated stress field around the northwest margin of the Kanto Plain (Kanto-heiya-hokuseien) fault zone and Tachikawa fault zone based on focal mechanisms of microearthquakes. Focal mechanisms have been determined from P-wave polarity data as well as body wave amplitudes for about 400 microearthquakes that occurred around those fault zones between June 2002 and December 2011. The main results are summarized as follows:

(1) Most of earthquakes show a reverse faulting mechanism, while earthquakes with strike-slip faulting components are also occurring throughout the region.

(2) A stress field suddenly changes across the Kanto-heiya-hokuseien fault zone. P-axes on the northeast side of the fault zone are oriented in the E-W direction, which is consistent with an overall stress regime in northeast Japan. In contrast, those on the southwest side are oriented in the NE-SW direction.

(3) The region with P-axis of NE-SW direction is estimated to extend to at least 50 km away from the surface trace of the Kanto-heiya-hokuseien fault zone.

On the basis of the above features, we discuss the relation of the present-day stress field with the geologically estimated slip sense of both fault zones.

Acknowledgements. The seismograph stations used in this study include permanent stations operated by NIED (Hi-net), JMA, and ERI. We modified a program coded by Satoshi Ide for estimating focal mechanism solutions.

Keywords: the Kanto Plain (Kanto-heiya-hokuseien) fault zone, Tachikawa fault zone, microearthquake, focal mechanism, stress field

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SCG65-P02 Room:Convention Hall Time:May 19 18:15-19:30

Stress and effective frictional coefficient estimated by micro-fault inversion method in Chi-Chi seisimogenic fault, Tai

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Introduction: Stress changes spatially and temporally in seismic cycles. Chelungu-pu fault is a seismogenic reverse fault that can be drilled from on land. In Taiwan Chelungu-pu Fault Drilling Project (TCDP) detailed structural data was obtained from drilled core. Additionally the surface rupture zone of the fault is well traceable in surface topography. In this study, we estimated paleo stress and effective friction coefficient from micro-faults, and then, discuss the relationship between spatial and temporal changes of stress and seismic cycles.

TCDP core: Deformation structures such as micro-fault, open crack, and fault rock were described from TCDP core observation. Slip data including displacement orientation and slip sence is obtained from slickenlines, rake and slickensteps. Calcite vein accompanies with some micro-fault or open crack.

Fault data from on land outcrops: In order to compare with slip data of TCDP core, we gathered slip data from a surface rupture zone on land. The surface rupture zone exposes 450m long along the river located at southern part of Dakeng Earthquake Park. Lithofacies is composed mainly by gray shale and slightly thick sandstone. Most of micro-fault which we could get slip data presented in range of 100m.

Grouping of slip data: We classified slip data into two, as the hangingwall side (T1) and footwall side (T2). The boundary is at 1153m. We have classified the micro-fault as that with vein, vein (T1c or T2c), without vein (T1n or T2n), fault zones (FZ), all of data (ALL) for TCDP data. Slip data from surface rupture zone is classified into 4 on the basis of resulted stress ratio (s1-s4). Stress ratio shown in phi=(sigma2-sigma3)/(sigma1-sigma3). Number of the slip data is following, ALL is 153, Fz is 10, T1c is 33, T1n is 65, T2c is 27, T2n is 31, s1 is 32, s2 is 26, s3 is 28, and s4 is 28.

Micro-fault inversion method: We used inversion method Hough transformed inversion method (HIM) (Yamaji et al., 2006) that uses Hough conversion. We estimated effective friction coefficient mu from minimum of the ratio of normal stress to shear stress on each micro fault.

Result: Direction of compressional axis for ALL, T1c, and T1n are WNW-ESE, NNW-SSE for FZ and EW for T2c and T2n. As a consequence, directions of compressional axis for T1 and T2 are different at the boundary of fault zone 1153m. Direction of compressional axis from surface rupture zone, for s2 and s4 are WNW-ESE, NNW-SSE for s1 and NS for s3.

Over all, stress ratio estimated from drilled core represent a small, about 0.008-0.274. The stress ratio from surface rupture zone is 0.0194-0.6448. Effective friction coefficient mu of core is 0.08-0.70 for ALL, 0.51 for FZ, 0.74 for T1c, 0.18-0.65 for T1n, 1.14 for T2c, 0.51-1.44 for T2n. Mu of surface rupture zone in 0.04 for s1, 0.08 for s2, 0.13 for s3, and 0.09 for s4. Mu of T1 is higher than that of T2.

Discussion: Compressional direction of T1 coincides with the direction reported in Lin et al (2010) which estimated the modern stress state by borehole breakeout. T2 direction, however, indicates slightly different from the modern state. s2 and s4 show almost the same direction as T1 direction. s1 is consistent with that in FZ. Lin et al (2010) also represented that compressional direction rotated about 90 degree from other place in vicinity of fault zone. Compressional direction of s3 is rotated but the rotation is only about 60 degree. High effective friction coefficient of micro-fault with veins suggests low fluid pressure along the fault. Micro-faults without vein are expected relatively high fluid pressure, which reduce effective frictional coefficient. Stress ratio for FZ shows one order lower than the others, suggesting that the fault zone was formed under large axial compression in seismic events.

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SCG65-P03 Room:Convention Hall Time:May 19 18:15-19:30

Distribution of fault plane solutions of smaller events associated with transcurrent movement of Kuril fore-arc sliver

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Using the method developed by Imanishi et al. (2006), Sugawara et al. (2010, 2011) determined fault plane solutions of smaller events to find the evidence of transcurrent movement of fore-arc sliver along the southern Kuril trench. They used P- and SH-waves amplitudes as well as P-wave polarity data and determined fault plane solutions of smaller events with magnitude range from 2.0 to 3.5 and the numbers of P-wave polarity data are 10 or greater. Especially, they focused on the fault plane solutions of events along the estimated boundary of the fore-arc sliver in Hokkaido. Hiratsuka et al. (2012) investigated the spatial distribution of P-axes and T-axes of those fault plane solutions determined by Sugawara et al. (2010, 2011) in more detail. As results, WNW-ESE trending P-axes are distributed along the volcanic front, which is consistent with transcurrent movement of Kuril fore-arc sliver. Under the Hidaka Mountains, ESE-WNW trending P-axes are distributed along the upper interface of subducted Pacific plate. P-axes sub-parallel to the Kuril trench is distributed in the western side of Hidaka Mountains, which is consistent with ongoing process of collision between Kuril fore-arc sliver and Northeastern Japan arc. Strictly speaking, azimuth of P-axes near the hypocenters of 1970 Hidaka earthquake (M6.3) and 1982 Urakawa-oki earthquake (M7.1) are oriented SW-NE direction, while in the surrounding region they are oriented WSW-ENE direction. These results may imply that at least three different stresses act on the vicinity of the Hidaka Mountains.

In order to estimate stress field in the vicinity of Hidaka Mountains, we applied the multiple inverse method (Yamaji, 2000; Otsubo et al., 2008) to the fault plane solutions of smaller events determined by Sugawara et al. (2010, 2011). On the basis of azimuthal distribution of P-axes, we assumed the existence of three different stresses and estimate the direction of their principle stress axes and stress ratio ((sigma2-sigma3)/ (sigma1-sigma3)). We discussed the origin of those stresses based on the calculation of stress field for a homogeneous half-space using the formulae developed by Okada (1992) and comparison with 3D seismic velocity structure inferred by Nakamura et al. (2008).

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