Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SCG061-01 Room:302 Time:May 25 16:30-16:45

Anomalous depth dependency of the stress field in the 2007 Noto Hanto, Japan, earthquake: Potential involvement of a dee

Aitaro Kato[1*], Shin'ichi Sakai[1], Takashi Iidaka[1], Takaya Iwasaki[1], Eiji Kurashimo[1], Toshihiro Igarashi[1], Naoshi Hirata[1], Toshihiko Kanazawa[1], The group for the joint aftershock observation of the 2007 Noto Hanto Earthquake[1]

[1]ERI University of Tokyo

We have elucidated depth variations in the stress field associated with the 2007 Noto Hanto, Japan, earthquake by stress tensor inversion using high-quality aftershock data obtained by a dense seismic network. Aftershocks that occurred above 4 km in depth indicated a strike-slip stress regime. By contrast, aftershocks in deeper parts indicated a thrust faulting stress regime. This depth variation in the stress regime correlates well with that in the slip direction derived from a finite source model using geodetic data. Furthermore, the maximum principal stress (S1) axis was stably oriented approximately W20N down to the depth of the mainshock hypocenter, largely in agreement with the regional stress field, but, below that depth, the S1 axis had no definite orientation, indicating horizontally isotropic stress. One likely cause of these drastic changes in the stress regime with depth is the buoyant force of a fluid reservoir localized beneath the seismogenic zone.

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SCG061-02 Room:302 Time:May 25 16:45-17:00

Comparison between the seismologically determined stress and the geologically determined slip direction along an active

Satoshi Tonai[1*], Norio Shigematsu[1], Kazutoshi Imanishi[1], Takashi Azuma[1], Kazuo Mizoguchi[2], Tomoyuki Ohtani[3], Ryosuke Kutsuna[3]

[1]Geological Survey of Japan, AIST, [2]CRIEPI, [3]Gifu University

We compared the seismologically determined stress solution and the fault-slip data observed at the outcrops along the Atera fault, Central Japan, to understand relationship between the crustal stress and the slip directions of active faults. The seismologically determined stress solution can account for all of the fault-slip data obtained from the main fault plane, whereas that cannot account for all of the fault-slip data apart from the main fault plane. The Atera fault is a NW-SE trending active sinistral strike-slip fault at the eastern part of Gifu Prefecture with high deformation rate and is one of the best studied active faults in Japan.

The seismologically determined stress solution was calculated by a stress tensor inversion technique (Michael, 1984) using the focal mechanism solutions of 22 microearthquakes that occurred around the study area between October 2003 and October 2010. The focal mechanism solutions consists mainly of reveres-faulting type and we obtained the stress solution with the maximum principal stress S1 oriented horizontally NW-SE or WNW-ESE. Misfit angles between the slip direction and the shear stress direction predicted by the stress solution are less than 30^o for all focal mechanism solutions, so we regard the stress solution as the crustal stress in the study area.

The fault-slip data were obtained at five outcrops of the Atera fault which was already reported by previous studies. Four of the outcrops are within 5 m and the other is about 100 m away from the main fault plane of the Atera fault. We observed more than 100 slickenlines on fault planes and acquired 58 fault-slip data composed of fault orientation, slip orientation, and sense of slip. Quite a few fault planes strike NW-SE and dip to the northeast and show dextral and sinistral strike-slip. Few fault planes show reverse fault. Crosscutting relationship among fault planes was not found.

We calculated a misfit angle of each fault-slip data for the stress solution and found that only about 20% of fault-slip data have misfit angle less than 30^o for the seismologically determined stress solution. It should be noted that all fault-slip data obtained from the main fault plane (5 data) show a small misfit angle less than 30^o, whereas those obtained apart from the main fault plane (0.3-100 m from the main fault plane) have a wide range of misfit angles. This variability of misfit angles indicates that slickenlines in the fracture zone have been formed by several different stresses. Small-scale spatial variation of stress regime in the fracture zone of an active fault may account for the variability of misfit angles. The other possibility is that the slickenlines have not been formed by the present stress regime but the geological paleostress regimes due to the long active history of the Atera fault.

A part of this research project has been conducted as the regulatory supporting research funded by the Nuclear and Industrial Safety Agency (NISA), Ministry of Economy, Trade and Industry (METI), Japan. The seismograph stations used in the microearthquake analysis include permanent stations operated by NIED (Hi-net), JMA, ERI, Nagoya University, and DPRI.

Keywords: Atera fault, active fault, microearthquake, focal mechanism solution, stress tensor inversion, minor fault

Japan Geoscience Union Meeting 2011
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SCG061-03 Room:302 Time:May 25 17:00-17:15

Multi anisotropy observations in the vicinity Chelungpu fault near Dakeng, Taiwan

HungYu Wu[1*], Ito Hisao[1], Ma Kuo-Fong[2]

[1]JAMSTEC, [2]National Central University

The 1999 Chi- Chi earthquake (Mw=7.6) take place in Taichung, Central Taiwan. The high rupture velocity and displacement record in northern part of Chelungpu fault. The total rupture length over 100 km and width large 35 km, the rupture propagated from south to north and the bending in the north end extend to East-West direction. The mainshock is pure thrust fault in the south and thrust with strike-slip type in the north. After the contentious drilling to 2 km depth, TCDP Hole-A collected various geophysical downhole measurements to determine the physical properties near the active fault. The Dipole Sonic logs (DSI) and Formation micro imagers (FMI) data are discussed, the velocity anisotropy amount and fast shear azimuth can be analyzed in DSI and the stress azimuth variation was displayed in image logs. The DSI result indicated the apparently anisotropy decreasing with the depth, the significant low anisotropy is occurred near the fault zone. Comparison with both stress indicating logs, shows that the most dislocation of azimuth in each log is close to the depth 1110 meters and consistence with the borehole breakout rotation. The rotation patterns are in agreement with each other cased by stress-induced anisotropy.

Keywords: DSI, Anisotropy, Stress roatation, Breakout, Chelungpu fault, FMI

Japan Geoscience Union Meeting 2011
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SCG061-04 Room:302 Time:May 25 17:15-17:30

Stress state estimate by geophysical logs in NanTroSEIZE drilling project site C0009

Hisao Ito[1*], HungYu Wu[1]

[1]JAMSTEC

To determine the fault mechanism and seismogenic zone in NanKai Trough, NanTroSEIZE investigated 1.6 km (mbsf) riser drilling in the central Kumano forearc basin to characterize the geophysical properties for future drilling through the megasthrusts. There were several downhole measurements run in this pilot drilling including image logs, caliper and comprehensive geophysical logs sets. The borehole breakout and lack of the drilling induced tensile fractures in this reprocessing image logging indicated the direction of the minimum horizontal compressive stress (Shmin), which show the consistent with the far-field stress direction. If the borehole breakout observation in the possible accretionary prism are representative the relationship with the rock strength and horizontal principal stresses, the different behaviors of borehole rock failure emphasize the variation of horizontal principal stress ratio. In this paper, we constrain the possible magnitude and orientation of horizontal principal stress. The stress induced shear wave anisotropy in Unit III and breakout azimuth in Unit IV are suggested that the direction of SHMAX in this well parallel to the direction of Philippine sea plate to Japan motion. Despite there is uncertainty of rock strength, the P-wave velocity profile shows the less variation with the depth represent the change of rock strength in the small level. The lack of breakout and tensile fractures in Unit III are attributed to the effective hoop stress acting on the borehole wall are less than the rock strength, which implied there are lower difference of horizontal principal stress. The higher differential horizontal principal stress in Unit IV caused the presence of breakout as we observed in the resistivity image logs.

Keywords: NanTroSEIZE, FMI, Boorehole breakout, Rock strength, Effective stress

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SCG061-05 Room:302 Time:May 25 17:30-17:45

Fault formation and stress change in the frontal zone of an accretionary wedge: Insight from numerical simulation

Ayumu Miyakawa[1*], Takeshi Tsuji[1], Yasuhiro Yamada[1], Toshifumi Matsuoka[1]

[1]Kyoto University

We studied a relation between a fault formation and a stress change in the frontal zone of an accretionary wedge using numerical simulation. We modeled a formation process of an accretionary wedge by using the Distinct-Element method. We observed the fault activities and measured dynamic stress state in the numerical model.

Frontal thrusts were formed in the sediments in front of the wedge, and the displacements of the active frontal thrusts were large. On the other hand, intermittent reactivations with small displacement of the existing faults were observed in the wedge, though the new faults were not formed in the inside of the wedge.

Relatively isotropic and vertical compressional stress state was observed in the sediment far from the toe of the wedge. However, as coming closer to the toe of the wedge, the stress state change into anisotropic, and high and horizontal compressional stress is observed in front of the wedge. After the sediments were incorporated into the wedge, the direction of the maximum compressional stress inclined to trench ward and the stress state was changed into isotropic. The compressional stress was recovered to the horizontal as the wedge growth, but the increase of principal stress ratios was still small.

The relation between fault activity and stress change is summarized based on these results. Frontal thrusts were formed by the dominant horizontal compressional stress, which is caused by the plate subduction, in front of the wedge. The activities of the frontal thrusts release the stress, and the stress state is changed into isotropic. The frontal thrust is not able to be active under this isotropic stress state, and new frontal thrust is formed within the sediments under the anisotropic stress state in front of the wedge. On the other hand, horizontal compressional stress is increased again by the stop of the fault activity in the inside of the wedge. The existing faults are reactivated in the increasing horizontal state and release the stress by their activities before a formation of a new fault. To form new faults (out-of-sequence thrusts) within the wedge, particular mechanisms are necessary that existing faults are to be inactive and that an anisotropic stress state is to be generated.

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SCG061-06 Room:302 Time:May 25 17:45-18:00

Application of Compact Conical-Ended Borehole Overcoring Technique for Initial Stress Measurement of Discontinuous Rocks

Yuji Tsubota[1*], Daisuke Kashima[1], Hideaki Nohara[1], Koji Yamaguchi[2]

[1]The Chugoku Electric Power Co., Inc., [2]Chuden Engineering Consultants Co., Ltd.

Japanese Only

Keywords: Discontinuous Rocks, The Compact Conical-Ended Borehole Overcoring Technique, Initial Stress Measurement

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SCG061-07 Room:302 Time:May 25 18:00-18:15

Heterogeneous stress analysis and Shmax trajectories around Shikoku

Atsuki Kubo[1*], Masami Koike[2]

[1]Earthq. Obs. Fac. Sci. Kochi Univ., [2]Fac. of Sci. Kochi Univ.

Philippine Sea Plate is obliquely subducting beneath Shikoku. Shikoku is also close to backarc opening region toward west. Thus stress state in Shikoku is very important to understand dynamics of oblique subduction and/or backarc opening. To reveal stress field, we use focal mechanisms and stress inversion technique. We determined focal mechanisms using observations of our observatory and exchanged data among other institutes and universities since 1995. We obtained 1950 high accuracy focal mechanisms (depth lt 20 km). Stress inversions using these results are conducted for 29 divided regions. We use multiple inverse technique for the stress inversion (Yamaji, 2010). Number of stress solutions within subregions are adjusted to 2 or 3 using analyzed results. Obtained stress solutions shows 4 stress provinces(1) Shikoku, 2) near MTL, 3) Sanyo, 4) Sannin,) across arc. In contrast, along arc variation, extensional stress states appear in Iyonada, Takanawa, Bungo-channel, Western Shikoku in addition to widely distributed compressional stress state. This extensional stress shows N-S extension which is different from those of Terakawa and Matsu'ura (2010) (E-W extension). Trajectories of Shmax directions are drawn using obtained stress states based on Lund and Townend (2007). Obtained trajectory map is similar with that obtained from geological research (Tsukuda, 1992).

Keywords: Stress field, focal mechanism, Maximum horizontal compression, Shikoku

Japan Geoscience Union Meeting 2011
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SCG061-08 Room:302 Time:May 25 18:15-18:30

Kinematics of the mylonite controlled by the stress regime

Norio Shigematsu[1*], Koichiro Fujimoto[2], Nobuaki Tanaka[2]

[1]Gelogical Survey of Japan, AIST, [2]Tokyo Gakugei University

The kinematics of mylonite is usually discussed based on the orientation of foliations, lineations, and microstructural asymmetric structures in structural geology. The relationship between the kinematics of the mylonite and the stress field has not been quantitatively evaluated previously. In this study, we examine the relationship within the mylonite developed along the Median Tectonic Line, in the eastern Kii peninsula in Japan.

The Geological Survey of Japan, AIST (GSJ, AIST) recently constructed an integrated groundwater observatory close to the MTL in the eastern Kii peninsula in Japan, and borehole core sample which penetrates the MTL was obtained during the construction. We used the fault slip data acquired in this core sample for the analysis.

The orientation of the foliations and lineations in the mylonite is gradually changed towards the MTL. Foliations dip to NNE or NE and the lineations plunge shallowly to east in the region apart from the MTL. Foliations dip to NNW and lineations plunge ENE and some of the lineations plunge steeply to the direction from NE to east in the vicinity of the MTL. These suggest that sigmoidal shaped foliations are developed within the mylonite along the MTL, and shear strain gradually increase toward the center of the shear zone.

The stress inversion based on the orientations of the foliations and lineations in the mylonite yield the stress field where the maximum stress axis is oriented WSW and stress ratio (=(S2-S3)/(S1-S3)) is approximately 0.2. The calculated orientations of the resolved shear stress for the sigmoidal shaped foliations are almost parallel to the observed orientation of lineation, i.e. the kinematics of the mylonite is controlled by the stress regime.

It has long been believed that the mylonite along the MTL shows the sinistral sense of shear. This is the case in weakly deformed mylonite. However the stress regime during the mylonitization resulted in the steeply plunging lineations in the vicinity of the MTL, suggesting the considerable component of reverse fault along the MTL during the mylonitizaion. The kinematics of the mylonite controlled by the stress regime may also influence the stress accumulation for the earthquake generation.

Keywords: Kinematics, Stress regime, mylonite, resolved shear stress, the Median Tectonic Line

Japan Geoscience Union Meeting 2011
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SCG061-P01 Room:Convention Hall Time:May 25 14:00-16:30

Improvement of stress tensor inversion by the revision of computational grid

Atsushi Yamaji[1*], Katsushi Sato[1]

[1]Div. Earth Planet. Sci., Kyoto Univ.

We improved a stress inversion method using a spherical code, which was a set of 60,000 points distributed with more or less uniform intervals on a unit sphere in 5-dimensional Euclidean space. The distribution was determined numerically by minimizing the total Coulombic potential of 60,000 charged particles constrained on the sphere. This optimization ran on a personal computer for 3 months.

The points represent 60,000 different stress states with 'uniform' intervals, which can be used as the computational grids in stress inversion methods.

We tested the multiple inverse method using the conventional and the new grid points. For this purpose, artificial data were generated with assumed stresses. The result of the method was significantly improved by the spherical code.

Keywords: stress tensor inversion, tectonics, spherical code, focal mechanism, fault

Japan Geoscience Union Meeting 2011
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SCG061-P02 Room:Convention Hall Time:May 25 14:00-16:30

Simultaneous determination of tectonic stress field and individual focal mechanisms from seismic amplitude data

Kazutoshi Imanishi[1]*

[1]Geological Survey of Japan, AIST

The stress tensor inversion method solves for the orientation of the three principal stress axes and the relative magnitude of the principal stresses using suites of fault slip data. In seismology, focal mechanisms are generally used as the basis for searching the best fit stress model (e.g., Gephart and Forsyth, 1984; Michael, 1984). In the 90s, a sophisticated approach by inverting directly from polarity data of P-wave to a stress tensor was proposed (e.g, Horiuchi et al., 1995; Loohuis and van Eck, 1996; Abers and Gephart, 2001). In this study, we try to extend the approach by using seismic amplitude data, together with P-wave polarity.

The inversion procedure consists of two nested grid searches. The outer search is conduced over a range of the stress tensor, where the principal stress axes and stress ratio are gridded with an appropriate step size. The inner search is conducted to identify a focal mechanism for each earthquake that best fit the observations by testing stress-consistent focal mechanisms (SFM). Here SFM is the suite of focal mechanisms whose fault plane can have any orientations, but the slip direction must be aligned with the shear stress direction predicted by the stress tensor of the outer search. By summing the residual of each earthquake, we determine the misfit of the stress model (S). As a result of the two nested grid searches, we obtain the best stress tensor that minimizes the misfit S and individual focal mechanisms. In this study, we call the present method ”ASTI (Amplitude-based Stress Tensor Inversion)” and the original method using polarity alone ”POSTI (Polarity-based Stress Tensor Inversion)”, respectively.

In order to investigate the performance of ASTI and POSTI, we conducted numerical tests using synthetic data set. We generated 20 earthquakes whose fault planes were oriented in random directions. The slip direction of each fault plane was calculated so that it aligns with the shear stress direction predicted by the assumed stress tensor. Random angle values with the standard deviation of 10 degrees were added to the slip directions. For each earthquake, 20 observations (P-wave polarity and amplitude) were calculated. The result of the numerical test indicates that a correct solution of the stress tensor was determined by both methods, though some fault planes were incorrectly determined in the case of POSTI. When we decreased the observations for each earthquake down to 10, the ASTI method still succeeded in estimating the true stress tensor, while the POSTI method failed.

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Keywords: stress field, focal mechanism, seismic amplutude data, stress tensor inversion

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Importance of stress distance in stress inversion analysis and its physical meaning

Katsushi Sato[1*]

[1]Div. Earth Planet. Sci., Kyoto Univ.

Stress inversion methods are widely used to infer crustal stress states from fault-silp data. For the purpose of detecting different stresses separately from a heterogeneous fault-slip data set, we need to measure the difference between stress tensors. A statistical assessment of optimal stress solution or a comparison of solutions obtained through several methods also requires a measure of difference. However, it is not easy to define the difference of tensors. The unknown of stress inversion analysis is called reduced stress tensor, which carries the orientations of three pricipal stress axes and a stress ratio, the shape factor of stress ellipsoid. The problem is how to synthesize the differences in orientations and stress ratios.

Orife and Lisle (2003) proposed a solution to this problem. They calculated so-called ”stress difference” between various stress tensors, which is defined as square root of second basic invariant of the difference tensor of two tensors, and showed its convenience. For example, given a nearly axial compressional stress with magnitude of sigma3 comparable to sigma2, a rotation around sigma1-axis yields small value of stress difference, while a rotation of sigma1-axis is evaluated as large difference. Although the stress difference was useful, its characteristics were clarified only empirically and its physical meaning remained unclear.

The physical meaning was given by Yamaji and Sato (2006). The stress difference approximately has one-to-one correspondence to the expected angular difference in shear stress directions on a randomly-oriented fault surface exerted by two stresses in comparison. In other words, the difference in stress tensor can be measured by that in fault-slip direction according to the Wallace-Bott hypothesis, which states a fault slips in the direction of shear stress. This fact means that the stress difference is suitable for solutions of stress inversion analyses based on the hypothesis.

The author recently found that the above-mentioned physical meaning was not exact. The stress difference turned out to be analytically equivalent to the expected difference in shear stress vectors on a randomly-oriented fault surface. The differences not only in directions, but also in magnitudes of shear stresses are involved in a value of stress difference. This discovery is inconvenient for the usage of stress difference in inversion analyses in which the magnitudes of stress are normalized. We need to pay attention to the fact that the way of normalization inevitably affects the values of stress differences.

References

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Yamaji, A. and Sato, K., 2006. Geophys. Jour. Int. 167, 933-942.

Keywords: stress tensor inversion, stress difference, angular stress distance, fault-slip data, deviatoric stress space

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Method and significance to determine stresses from heterogeneous fault-slip data obtained in different depths

Makoto Otsubo[1]*

[1] AIST/IGG

We will present the significance to determine stresses from heterogeneous fault-slip data obtained in different depths and the result of applying the multiple inverse method (Yamaji, 2000; Otsubo and Yamaji, 2006) the data. We can obtain the data from outcrops, borehole cores and focal mechanisms. A heterogeneous data set comes also from a rock mass in which the state of stress changes spatially and/or temporarily.

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Keywords: Stress, Fault-slip data, Multiple inverse method, Tectonics, Crust, Earthquake

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Incremental fold test for stress tensor inversion based on fitness evaluation to fault-slip data

Satoshi Tonai[1*], Katsushi Sato[2], Juichiro Ashi[3]

[1]AIST, [2]Kyoto University, [3]AORI, the University of Tokyo

We present a method of incremental fold test for the paleostress inversion of fault-slip data obtained from folded sedimentary rock, which provides not only the orientations of the three principal stress axes and the stress ratio, but also the relative timing of folding and faulting. The method is based on the stepwise backtilting of strata that was tilted before, during, or after fault activity. At each step, the rotated fault-slip data are analyzed by a stress inversion technique, based on the Hough transform. The inversion technique calculates the degree of fitness of all possible stresses to the fault data and detects the optimal fitness. The peak values of fitness are compared among the various backtilting steps to find the maximum value. The stress and the backtilting step that yield the maximum fitness are selected as the optimal solution. To assess the validity of the method, we applied it to artificial fault-slip datasets generated with hypothetical histories of folding and faulting and with known paleostresses. The proposed method succeeded in determining the supposed stresses and the relative ages of folding and faulting.

Keywords: minor fault, stress inversion, fold test

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Relation between formation of echelon faults and stress fields in rock mass-Simulation using MPS method-

Yuki Imai[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

[1]Kyoto Univ.

Echelon faults are a group of cracks and faults which have a certain angle to the main shear faults caused by earthquakes and crustal deformation. In Japan, they can be observed off the coast of Izu Peninsula. The mechanism and formation of the echelon faults are not well investigated, and there still remains an important geophysical subject to look into. In this study, we try to simulate the formation of echelon faults to investigate the nucleation conditions by the MPS (Moving Particle Semi-implicit) method which is a particle method developed for incompressible flow analysis. Particle interaction models for differential operators are prepared in this method. The government equations of elastic structures are interpreted into interactions between particles. In the finite difference and the finite element method, the failure at faults or cracks would not be well simulated when the displacement becomes large or the grid-based structure is broken. Particle methods are free from this difficulty. We simulate uniaxial and triaxial compression of 2D rectangle elastic structure. In the triaxial compression, we change the cohesion and the confining pressure to investigate the relation to the form of echelon faults. Our results show that the conjugate faults or cracks are generated with higher density as the cohesion and the confining pressure becomes higher. This suggests that we could estimate the magnitude and the direction of stress in rocks from the distribution of echelon faults.

Keywords: echelon, particle method, MPS method, compression test