Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-01 Room:201B Time:May 23 16:15-16:30

Visualizations of crustal deformation of Japan using GSI GEONET data

Tadayoshi Kato[1*], Yasushi Harada[1], Toshiyasu Nagao[2], Teruyuki Kato[3]

[1]School of Marine Science and Technology, Tokai University, [2]Earthquake Prediction Research Center, Tokai University, [3]Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo

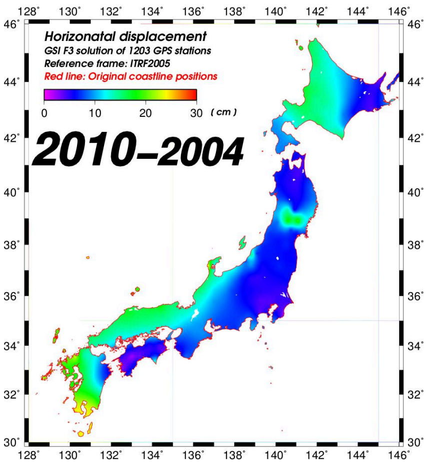
The Geographical Survey Institute of Japan(GSI) has about 1300 GPS station(GEONET) in Japan for more than 18 years observing Japanese inland crustal deformation, and the GEONET has enable us to watch how Japan is continuously deforming at a rate of a few cm/year. By utilizing the GEONET data, we succeed in visualizing how Japanese islands move, deform, elevate with time, with no limitations such as types of data, time intervals, area, and types of visualization methods.

From the animation, we can easily understand the deformations in Japan before and after the March 11, 2011 earthquake. However, it is difficult to understand the rates of accumulation for the deformations. In this study, the displacements of GPS stations and the strain distributions using Delaunay triangulation method are used for the visualization. In addition, an animations of Japanese crustal deformation with time series of epicenters are also created.

It is important to create animations of Japan using various data sets such as topography, gravity anomaly, seismicity, displacement velocity, and strain distribution to detect anomalous events. Prompt recognition of these events may help the Japanese people to prepare for natural disaster such as big earthquakes and tsunamis. Finally, it is also important to utilizing this kind of animations in school education for kids to recognize Japanese crustal activities.

All animations created in this study is downloadable at
http://kutty.og.u-tokai.ac.jp/~harada/

Keywords: Japan, Crustal motion, GPS, GEONET, Visualization



Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-02 Room:201B Time:May 23 16:30-16:45

Estimation of the viscoelastic relaxation following the 2011 off the Pacific coast of Tohoku earthquake

Hisashi Suito[1]*

[1]GSI of Japan

We are developing a 3-D viscoelastic model using the Finite Element Method to describe the postseismic deformation following the 2011 Tohoku-oki earthquake. The purpose of this presentation is how much viscoelastic relaxation contributes to the observed postseismic deformation. The viscoelastic relaxation strongly depends on the value of the mantle viscosity. The previous studies reported that a range of mantle viscosity under the Tohoku district is estimated to be 10^{18} to 10^{19} Pas. I computed the viscoelastic relaxation using a range of mantle viscosities 10^{17} to 10^{20} Pas.

Our model suggests that viscoelastic relaxation contributes to the observed 21 months postseismic horizontal displacement significantly in the Tohoku area when the viscosity is less than 10^{18} Pas. In this case, however, viscoelastic relaxation exceeds the observed displacement at the Japan Sea side.

In the case of the viscosity of 10^{19} Pas, our viscoelastic model predicts eastward velocity of 5 cm/yr in the Tohoku district for the first a few years. This eastward velocity lasts at least more than 30 years.

Keywords: Tohoku-Oki Earthquake, postseismic deformation, viscoelastic relaxation

SSS34-03 Room:201B Time:May 23 16:45-17:00

Deformation of the Nankai forearc sliver and Median Tectonic Line

Takao Tabei[1*], Atsuki Kubo[1], Shozui Ichitani[2], Mikito Tanaka[2], Yasuhiko Nakamura[2], Yuichi Hasegawa[2]

[1]Faculty of Science, Kochi University, [2]Graduate School of Integrated Arts and Sciences, Kochi University

The Nankai forearc sliver in southwest Japan, which is bounded by the Nankai Trough plate boundary in the front and the right-lateral Median Tectonic Line (MTL) in the rear, has suffered from interseismic crustal shortening in the direction of plate convergence and long-term lateral movement along the MTL. In the east of the forearc, the arc-arc collision between northeast Japan and southwest Japan seems to drive the forearc lateral movement forward. In contrast, there is no driving force for the forearc movement in the west of the region because the plate boundary rotates counter-clockwise off eastern Kyushu and an obliquity in the direction of plate motion against the strike of the plate boundary disappears. As a result the forearc lateral movement is transformed into a block rotation in the eastern and southern parts of Kyushu. Thus the lateral movement of the Nankai forearc sliver characterizes the long-term crustal deformation field in southwest Japan and the MTL is related to the major deformation sources. In addition the MTL itself has a potential to generate a large inland earthquake in the future. We think it is important to understand subsurface structure and current slip/locking pattern of the MTL fault plane.

Recent seismic reflection survey has revealed a gently northward-dipping geological structure around the MTL (Ito et al., 2009). Horizontal displacement field from dense GPS networks across the MTL has shown a right-lateral relative motion between southern and northern blocks across the MTL but a transition zone of the displacement field is located 20-30 km north of the MTL (Tabei et al., 2002). These patterns are well explained by a forearc lateral movement affected by a shallow locking and a deep aseismic slip on a northward-dipping MTL fault plane. In contrast, there is another observation result that is inconsistent to an interpretation of the dipping fault plane. A series of earthquakes have aligned 20-30 km north of and parallel to the MTL and most of them show a right-lateral slip on a nearly vertical fault plane. Unfortunately station distribution of the nationwide seismic and GPS networks is rather sparse in the north of the MTL because of the existence of the Seto Inland Sea. In this area we have deployed supplementary 10 seismic stations equipped with short-period, high-sensitivity seismographs and 3 GPS stations with dual-frequency receivers and collected continuous data since November 2010.

We propose that several vertical right-lateral fault systems exist above the northward-dipping fault plane of the MTL and they act as s shear zone between the Nankai forearc sliver and the inner zone of southwest Japan. The width of the shear zone is estimated as 20-30 km from the GPS displacement field, which is consistent with the zonal distribution of characteristic P-axis directions of earthquakes but about half of the width of the Setouchi shear zone proposed from a geological point of view (Tsukuda, 1992).

Keywords: Median Tectonic Line, Nankai Trough, crustal deformation, GPS

SSS34-04 Room:201B Time:May 23 17:00-17:15

Recent crustal movements obtained by dense GPS network in the Tokai District

Mikio Satomura[1*], Yuuki Matsumoto[1], Keita Matsumito[1], Ryoya Ikuta[1], Seiichi Shimada[2], Teruyuki Kato[3], Yasushi Harada[4]

[1]Faculty of Science, Shizuoka Univ, [2]NIED, [3]ERI, Univ Tokyo, [4]Marine Sci and Tech, Tokai Univ

As the slow slip event was found by the GEONET observation conducted by the Geospacial Information Authority of Japan, in the Tokai District where a huge earthquake was expected to occur in the near future, JUNCO also made another dense GPS network there. We have reported some observation results such as the difference of crustal deformation during and after slow slip event and the detection of very small movements by the short-term slow skip events in the JpGU meetings.

We re-processed all data from 2004 in a unity condition by using GAMIT software and analyzed the characteristics of the recent crustal movements in the Tokai District.

1. Not only crustal movement velocities but also dilatation velocities were changed during and after the slow slip events. We had already reported that we could obtain the place of asperities on the surface of subducting Philippine Sea Plate by the forward calculation. The similar results were obtained by the inversion method.

2. We divided the duration from the end of the Tokai slow slip event to the 2011 Tohoku earthquake into two periods and investigated the crustal movement difference between the two. Smaller southward movements were obtained in the second period comparing in the first one referring to ITRF 2008. This would show that the coupling between the Philippine Sea Plate and Amurian Plate became stronger according to the time duration after the end of Tokai slow slip event.

3. We obtained the exponential components and linear trend ones in the movements after the 2011 Tohoku Earthquake. The co-seismic movements at the Earthquake had larger difference between north part and south one in the present investigation, comparing with these components. The exponential components are thought to be the influence of after-seismic fault motions and the linear trend ones are to be visco-elastic deformation effects, and therefore we think this difference shows the areal differences that areas of the after-seismic faulting and the visco-elastic deformation are wider than the Earthquake fault.

4. We obtained the dilatation velocity distribution after the 2011 Tohoku Earthquake. We can see the dilatant area in the north part and contract one in the south part of the investigation area. Eastward movements are large in the northeastern part and they are smaller in the northwestern part, but they are almost constant in the south part because of the coupling between the subducting Philippine Sea Plate and Amurian Plate.

Keywords: GPS, Tokai District, dense, slow slip, Tohoku Earthquake

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-05 Room:201B Time:May 23 17:15-17:30

Shallow slow-slip event detected by leveling survey at the central part of the Longitudinal Valley fault, eastern Taiwan

Masayuki Murase[1*], Nobuhisa Matsuta[2], Cheng-Hong Lin[3], Wen-Shan Chen[4], Naoji Koizumi[5]

[1]Department of Geosystem, College of Humanities and Sciences, NIHON University, [2]Graduate School of Environmental Studies, Nagoya University, [3]Institute of Earth Sciences, Academia Sinica, Taiwan, [4]National Taiwan University, [5]The National Institute of Advanced Industrial Science and Technology

Precise leveling survey was conducted across the central part of the Longitudinal valley fault, eastern Taiwan to discuss the detail deformation of the transition zone between the fault creeping area and asperity area. In order to focus on the relationship between the fault creeping area and rich melange distribution in the transition zone, we have established three leveling routes at the Yuli, Chike-san and Reishuei areas. The Yuli route is just located in the northern end of the rich melange distribution, but both Chike-san and Reishuei routes were established in the area where no rich melange exists. In the Yuli route, an uplift rate of about 30 mm/year has been detected from 2010 to 2012, suggesting the aseismic fault creep might be continuing with long-term. In the Chike-san route, the vertical deformation rate of about 8 mm/year was detected in the period from 2010 to 2011. However, there was the huge deformation with uplift rate of about 40 mm/year detected in the period from 2011 to 2012. In the Reisuei route, we detected the deformation of about 8 mm/year in the period from 2011 to 2012.

As explanations for the huge change of the deformation rate in the Chike-san route, we believe that the detected deformation has been resulted from a slow-slip event. Also since the significant deformations were not detected in leveling and GPS around Chike-san route, the slow slip event was localized to a small region just around the Chike-san route. Such a slow slip event might be triggered by the M 5.3 earthquake on June 14, 2012 because the number of micro-earthquakes in the Chike-san area rapidly increased after the M 5.3 earthquake.

We propose that the northern limit of the stable creeping area may be in the Yuli area and the slow slip event occurs in the transition zone between the fault creeping area and asperity area. The boundary between the creeping area and the slow slip area is basically consistent with the northern limit of the rich melange distribution.

Keywords: Taiwan, Longitudinal Valley fault, slow-slip, Precise leveling, fault creep, rich melange

SSS34-P01 Room:Convention Hall Time:May 23 18:15-19:30

SEQUENCE OF SIX M7-SIZED EARTHQUAKES IN THE NORTHEASTERN JAPAN PRECEDING TOHOKU-OKI EARTHQUAKE MARCH 11, 2011

Deasy Arisa[1*], Kosuke Heki[1]

[1]Department of Natural History Sciences, Faculty of Science, Hokkaido University

A sequence of M 7-class interplate earthquakes and postseismic slips following each of these earthquakes occurred along the Japan Trench before the occurrence of the giant earthquake on March 11, 2011. Several calculations of the earthquakes in northeastern Japan area including 2003 to 2011 M7-sized earthquakes are conducted to analyze the plate deformations on the Northeastern Japan. The analyzing processes include the measurement of the coseismic jumps of six M7?sized events occurring in October 31, 2003; August 16, 2005; May 8, 2008; July 19, 2008; March 14, 2010 and March 9, 2011. The postseismic slips which continuously occur following the earthquakes (some earthquakes in Miyagi, Fukushima, Iwate and Ibaraki) are also calculated. Both coseismic and postseismic slips are believed to closely relate to 3.11 Tohoku-oki earthquakes. Two mathematical models are used in the calculation and followed by the parameter adjustment using Okada formula to obtain the best parameter of the plate displacement. The parameter adjusted in Okada formula are included the length of displacement/rupture area, together with width, depth, dip angle, and dislocation length and rake angle. These parameters are then used to calculate the seismic moment and magnitude moment based on geodetic approach. These calculations revealed that the total moment released by these slips was much larger than the coseismic ones. These seismic moments will lead us to the conclusion about characteristic of coseismic and postseismic deformations in the Northeastern Japan area which differs from our understanding about the postseismic process that the postseismic deformation and slip are smaller than the coseismic deformations.

Keywords: Interplate earthquakes, Postseismic, Coseismic, Deformation, Slip, Seismic moment

SSS34-P02 Room:Convention Hall Time:May 23 18:15-19:30

Relation between the number of the aftershocks and the postseismic deformation of large earthquakes

Akio Kobayashi[1*], Daisuke MUTO[1], Hiroshi UENO[1], YOKOTA, Takashi[1]

[1]Meteorological Research Institute

Large earthquakes are followed by many aftershocks and postseismic deformation. Decay rate of aftershocks can be approximated by the Omori's power law. A postseismic deformation caused by a velocity-strengthening afterslip follows a logarithmic decay. A postseismic deformation caused by a viscoelastic relaxation follows an exponential decay. On the other hand, time series estimated from the seismic moments of small repeating earthquakes in the northeastern Japan subduction zone shows that the temporal change in afterslip follows a temporal power law (Kawada et al., 2009).

We compared the temporal evolutions of aftershock and postseismic deformation observed by the GEONET for some large earthquakes in and near Japan since 2000.A logarithm model may match the number of aftershocks as well as a power-law model. Both a power law model and a logarithm model may match for postseismic deformations of different earthquakes. In many cases the same model can be applied for aftershocks and postseismic deformations.

Keywords: number of aftershocks, postseismic deformation, modified Omori formula

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-P03 Room:Convention Hall Time:May 23 18:15-19:30

A rainfall correction of the strainmeter by the Radar-AMeDAS rainfall

Kazuhiro Kimura[1*], TSUYUKI, Takahiro[2], AKIYAMA, Kana[2], MISU, Hiromi[2]

[1]Meteorological Research Institute, [2]Japan Meteorological Agency

Kimura et al.(2012) tried to a rainfall correction of the JMA's volume strainmeter for forecasting of the Tokai earthquake, a tank model of three levels got a good result. It means that the reply of the strainmeter by the rainfall is effect of the load by the rainfall.

We try to a rain fall correction of the volume strainmeter by the Radar-AMeDAS rainfall. The true observation data of the precipitation in the neighborhood is most effective. If there is not such data in the neighborhood, The data of Radar-AMeDAS rainfall may be most effective. For a rainfall correction of the strainmeter, the precipitation of the observation point is the most important.

Keywords: Strainmeter, Rainfall correction, Tank model, SCE-UA method, Radar-AMeDAS rainfall

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-P04 Room:Convention Hall Time:May 23 18:15-19:30

The change of about 2010 to be seen in the long-term crustal strain observed in the Northern-Kinki region.

Kazuhiro Kimura[1*], Akio Kobayashi[1]

[1]Meteorological Research Institute

MRI(Meteorological Research Institute) is observing borehole-type multi-component strainmeters at Tsuruga and Imadu from 1996. Yamamoto and Kobayashi(2009) showed that the changes of about 2000 and 2005 in this long-term crustal strain consistent with the progress of long-term SSE at Tokai region and the direction of principal strain observed by GPS(GNSS).

This time, After correcting the long-term crustal strain by the Yamamoto and Kobayashi(2009) method, we recognized the change of about 2010. We research the comparison this change with GNSS(GPS) of the same period.

Keywords: crustal movement, strainmeter

SSS34-P05 Room:Convention Hall Time:May 23 18:15-19:30

Slow slip events in the Hyuga-nada, southwestern Japan

Shinzaburo Ozawa[1*], Yarai Hiroshi[1]

[1]Geospatial Information Authority of Japan

Post seismic deformation occurred after the Oct. 1996 and the Dec. 1996 earthquakes (Mw6.8, 6.9)in Hyuga-nada, southwest Japan. Decay time of this postseismic deformation was approximately estimated to be around 1.5 years. Afterslip of the earthquakes which caused post seismic deformation seems to have ended in 2004. However, slow slip event started from approximately 2005 in afterslip area. Hyuga-nada slow slip event seems to have a recurrence time of 2 years and duration of 1 year. Though Hyuga-nada slow slip is clearly observed after January 2005, there is a possibility that slow slip event occurred before January 2004.

Introduction

Post seismic deformation occurs after a large subduction earthquake. Post seismic deformation that is usually caused by afterslip follows logarithmical decay. The post seismic deformation after the 1996 Oct. and Dec. earthquakes decayed logarithmically until 2004. However, a slow slip event suddenly started from January 2005. We estimated the time evolution of afterslip and slow slip events and compared them.

Analytical Procedure

Spatial and temporal evolution of aseismic slip on the plate interface was estimated by the time dependent inversion.We firstly removed annual component and a linear trend from the raw time siries.We used time series without annual and trend components for the period between 1996 and 2013.A linear trend is estimated for the period between October 1 2008 and March 1 2009 during which there was no transient.We used approximately 60 GPS sites and weighed horizontal components and vertical components at a rate of 1:3 in the inversion.

Results and discussion

Our inversion result showed that afterslip occurred immediately after the occurrence of the main shocks. Afterslip gradually decayed and subsided approximately in 2004. However, a slow slip event started from January 2005 and subsided in Janaruy 2006 in the afterslip area. A next slow slip event started in January 2007 and subsided in January 2008 in a similar place. A slow slip event from January 2009 subsided in 2011 and there is no aseismic slip until January 2013. The time evolution of the estimated moment of aseismic slip for the period between January 1997 and January 2011 follows logarithimical decay with fluctuations. We cannot rule out a possibility that there occurred slow slip events before 2004.

Keywords: Hyuga-nada, slow slip event, afterslip

SSS34-P06 Room:Convention Hall Time:May 23 18:15-19:30

A variety of strain changes in the anticipated Tokai earthquake area

Tetsuo Takanami[1*], Naoshi Hirata[1], PENG, Hui[2], KITAGAWA, Genshiro[3], KAMIGAICHI, Osamu[4], LINDE, Alan T.[5], SACKS, Selwyn I.[5]

[1]ERI University of Tokyo, [2]CSU China, [3]Research Organization of Information and System, [4]Japan Meteorological Agency, [5]DTM Carnegie Institution for Science

Great interplate earthquakes have occurred at the Nankai Trough at a recurrence interval of approximately 100 to 150 years due to the subduction of the Philippine Sea plate beneath southwestern Japan. In addition to such a regular Nankai Trough earthquake cycle, there is a hyperearthquake cycle of 300 to 500 years. A Tokai earthquake has not occurred for more than 150 years since the 1854 Ansei Tokai earthquake. Tokai, Tonankai, and Nankai consolidated earthquakes have not occurred for more than 300 years since the 1707 Hoei earthquake. The Japanese government is taking the Tokai earthquakes seriously and has charged the Japan Meteorological Agency (JMA) with predicting the next one. There is now a dense array of instruments placed to accumulate a continuous stream of data related to seismicity, strain, crustal expansion, tilt, tidal variations, ground water fluctuations and other variables. They are watching for an anomaly in these data that might precede the next major Tokai earthquake. However the earth's surface is continuously influenced by of a variety of natural forces such as earthquakes, waves, winds, tides, air pressure changes, precipitation and by a number of human induced sources. These generate variations in geodetic data that may mask precursory signals. Eliminating unwanted changes in the raw data requires appropriate statistical modeling, for detailed and accurate processing of geodetic data. We show that applying state space modeling is valuable for removing extraneous influences in order to enhance detection of possible precursors of the anticipated Tokai earthquake. On 11 August 2009 the intraslab Suruga Bay earthquake (M6.5) occurred in the Philippine Sea plate under the Tokai area. The JMA network of strainmeters has already been monitoring short-term slow slip events (SSE) synchronized with nearby low frequency earthquakes or tremors since 2005 (Kobayashi, et al., 2006). Although the 2009 Suruga Bay earthquake was an intraplate earthquake in the Philippine Sea plate, it was immediately followed by a sudden increase in interplate earthquakes in the Tokai area for the following month (Aoi et al., 2010). No pre-slip was detected by land-based observations in the Tokai area, even though it appears that the post-stress state at the subducting plate boundary was strongly affected. We here try to isolate tectonic strain behavior before the 2009 Suruga Bay earthquake by applying the state space modeling and Kalman filtering/smoother to the volumetric strain data at the Tokai network of JMA. In summary we show: (1) The strain extracted by the state space modeling demonstrates that the shallow volumetric strainmeters deployed at depths less than 200m can provide high quality strain behavior. (2) The resulting strain time series can be divided into three groups: one composed of stations near Omaezaki, characterized by a very stable behavior; a second group, at large distance from the hypocenter, shows no significant changes; and a third group, the west coastal stations of Suruga Bay, is characterized by a synchronous change except for an irregular change just before the 2009 Suruga Bay earthquake. The unusual irregular changes occur at stations located on the landward side of tectonic boundary extended from Suruga Trough. Finally, the present study reveals an uncommon strain change just before the 2009 Suruga Bay earthquake.

Keywords: State space modeling, Volumetric strain data, 2009 Suruga Bay earthquake, Anticipated Tokai earthquake, Philippine sea plate, Slow slip event

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-P07 Room:Convention Hall Time:May 23 18:15-19:30

Temporal Change of Plate Coupling and Slow Slip Events in the Tokai-Tonankai Region in Japan

Tadafumi Ochi[1*]

[1] AIST

In the southwestern part of the Japanese Islands, many large earthquakes have been reported and many geodetic or seismic observations have been operated to monitor the crustal deformation due to the interplate process between subducting Philippine Sea plate and the overriding continental plate along the Suruga-Nankai trough. The precise observation provides us insight into aseismic stress releasing process such as (long-term) slow slip events (SSEs).

Although some part of accumulated stress in the hanging wall would be released by SSE, the interplate coupling always takes place in the surrounding area and affect stress accumulating process. Thus, monitoring temporal change of the interplate coupling is as important as that of aseismic events such as SSE. On the basis of this standpoint, the interplate coupling should not be treated as steady state but be inferred together with SSE.

I have done the geodetic inversion analyses for the Tokai region, which is the easternmost end of the Suruga-Nankai trough, and for the area around the Bungo Channel, which is near the westernmost part of the trough. The results of the former case are already reported (JpGU 2012, SSS32-10; Ochi and Kato, submitted). In both of the analysis, I mainly used the daily coordinate of the GPS(GNSS) data from 1996 to 2010.

In the Tokai case, the SSE occurred around the deeper edge of the distribution of the interplate coupling and the width of it in the dipping direction becomes narrower as the occurrence of the SSE. After cessation of the SSE, the distribution of the coupling does not return to the state before the SSE. Therefore, the SSE really affect the interplate coupling.

In the Bungo Channel case, on the other hand, the SSE also occurred around the edge of the distribution of the interplate coupling but had little effect on it. Therefore, the interplate states before and after the occurrence of the SSE are very similar and the interplate coupling can be regarded as the steady state in this case.

The obviously different nature between these two cases is the duration of the SSE; about five years in the Tokai case and one year in the Bungo Channel case. Considering the stress change on the plate interface, I will discuss the difference in the spatial pattern and underlying physics further.

Keywords: slow slip events, interplate coupling, GNSS

SSS34-P08 Room:Convention Hall Time:May 23 18:15-19:30

Topographic corrections for crustal deformations associated with earthquakes and volcanic activities

Hitoshi Goshima[1*], Shin'ichi Miyazaki[1], Takahito Kazama[1], Masayuki Kano[1]

[1]Kyoto University

Crustal deformations due to earthquakes and volcanic activities have been estimated, assuming a half-space elastic topography (Mogi, 1958; Okada, 1992). However, the half-space topography cannot reproduce the fault slips to the free surface at oceanic trenches such as the 2011 Tohoku earthquake.

We thus calculated topographic effects on the crustal deformations due to earthquakes and volcanic activities, according to Williams and Wadge (2000). We first considered boundary conditions of stress for undulating topography, and then solved them for the 0-th and the 1-st order terms of the crustal deformations (i.e., the half-space solution and the topographic correcting term, respectively). This method can reproduce both true fault depth and fault slips to the free-surface, as well as true elevation of observation stations. Moreover, this model can estimate realistic crustal deformations more easily than Finite Element Method (FEM).

We applied this method to the crustal deformation at Sakurajima Volcano (Takayama and Yoshida, 2007) with a spherical inflating source (Mogi, 1958), and found that the amplitude of the topographic correction term reached about 12 and 24 % (for vertical and horizontal displacements, respectively) of the half-space solution at most. We also applied the method to the crustal deformation due to the 2011 Tohoku earthquake (Geospatial Information Authority of Japan, 2011) using Okada (1992), and found that the amplitude of the topographic correction term reached about 10 and 9 % (for vertical and horizontal displacements, respectively) of the half-space solution at most, especially above the slipped faults.

In the future, we will solve inverse problems for the spatial distribution of the fault slip, using the observed GPS data at the 2011 Tohoku earthquake. Then, the topography-corrected solutions will be compared with the free-surface solutions and the FEM solutions, in order to evaluate the precision of the topography-corrected solutions.

Keywords: crustal deformation, topography, earthquake, volcanic activity, the 2011 Tohoku earthquake, Sakurajima Volcano

SSS34-P09 Room:Convention Hall Time:May 23 18:15-19:30

Crustal movement analyzed from GPS geodetic data and tectonic provinces in the Shin'etsu region, central Japan

Yuki Imai[1*], Akira Takeuchi[2]

[1]Graduate school of Science and Engineering for Education, University of Toyama, [2]Graduate school of Science and Engineering for Research, University of Toyama

The Shin'etsu region in central Japan is located in the Niigata-Kobe tectonic zone (Sagiya et al., 2000) and some moderate-sized inland crustal earthquakes, such as the Niigata Prefecture Chuetsu Earthquake in 2004 (M6.8), the Niigataken Chuetsu-oki Earthquake in 2007 (M6.8) and the Naganoken Hokubu Earthquake in 2011 (M6.7), occurred lately on end in this region. The concentration zone of crustal strain corresponds to the higher seismicity in the upper crust, and it is significant to understand the nature of crustal strain for discussing the generation mechanism of such crustal earthquakes in the back-arc belt. However, it is unclear how the geodetic strain-rate distribution relates geologically to the tectonic provinces. The purpose of this paper is to clarify the characteristics of crustal strain-rate distribution and mechanical relationship between the strain field and the tectonic provinces in the Shin'etsu region. Analyzing the GEONET geodetic data obtained in the last four and a half years, we evaluated the distribution of strain-rate in order to clarify crustal movement in the Shin'etsu region.

Contraction in a direction of WNW-ESE had substantially changed into large E-W extension at the moment of the 2011 off the Pacific coast of Tohoku Earthquake (M9.0). The distribution of strain-rate before and after the Tohoku earthquake is regionally heterogeneous. Before the Tohoku earthquake, the strain concentration zone revealed from GPS data extends in a NE-SW direction from Niigata to Matsumoto. This zone approximately corresponds to the late Cenozoic Niigata sedimentary basin and Minochi belt that have extremely thick sedimentary covers and the deep basement rocks. Moreover the distribution of strain-rate corresponds to the regional difference in thickness of the sedimentary veneers, it is likely that the crustal movement in the Shin'etsu region before the Tohoku earthquake was controlled by the differential movement of unit blocks in the tectonic provinces. The thick covers of sedimentary basins are more mobile than the rigid basement of the Echigo mountain range and the Central upheaval zone of Fossa Magna region. Thus it is possible that such a difference in mechanical property of the uppermost crust makes the regional heterogeneity of strain-rare. However, there is a mechanical model that a narrow zone of weakness in the lower crust accounts for the concentration zone of strain above (Iio, 2009). Thus the factors that affect the distribution of strain-rate on the surface are not only the regional difference in thickness of the veneer rocks but also the multiple controls included the behavior of the basements. In contrast, distribution of strain-rate after the Tohoku earthquake has no correspondence to the tectonic provinces. Because of large post-seismic displacement since the Tohoku earthquake, no characteristic pattern of strain-rate field corresponded to the tectonic provinces was recognizable. This suggests that the moderate signals as small as analyzed for the pre-seismic period might be hidden by such a large post-seismic deformation.

In order to understand the mechanism of strain concentration peculiar to the Shin'etsu region, it is necessary to continue our GPS geodetic observation for post-seismic deformation in order to investigate the behavior of lower crust of each tectonic province.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, crustal movement, strain concentration zone, tectonic province

SSS34-P10 Room:Convention Hall Time:May 23 18:15-19:30

Vertical movement during recent half year and gravity anomaly in the Murono mud volcano, Niigata, Japan

Shigekazu Kusumoto[1*], Keiya Sudo[2], Mika Kawabata[2], Yoichi Fukuda[3]

[1]Graduate School of Science and Technology for Research, University of Toyama, [2]Department of Earth Sciences, the Faculty of Science,University of Toyama, [3]Department of Geophysics, Graduate School of Science, Kyoto University

It is known that the surface in and around mud volcano located in Murono area, Matudai, Tokamachi City, Niigata, Japan, (we call this mud volcano simply the Murono mud volcano in the following) has been deformed extremely in vertical direction by large earthquake in the neighborhood. However, its inter-seismic vertical movement has not been known. In this study, we performed precise leveling periodically and attempted to obtain the inter-seismic vertical movement in the Murono mud volcano. We also performed precise gravity survey on the bench marks we set in the area and obtained Bouguer gravity anomaly, in order to estimate subsurface density structure in mud volcano and compare vertical movement with gravity anomalies.

The Murono mud volcano is the little mud volcano of the scale of length 100m and width 70m, and spouts gas and muddy water actively at present. We set up the bench marks of 61 in this mud volcanic area by the interval from several m to 20 m, and carried out the leveling of 5 times in June, July, October, November and December, 2012. We employed digital level for leveling, and obtained the elevation on each bench mark by the net adjustment. Accuracy of each observation was about 1.96mm/km. From observations during recent half year, we found that there are uplift reaching about 26 mm and subsidence of 14 mm in the Murono mud volcano. The uplift area obtained in this observation corresponds roughly to the uplift area obtained in the previous observations.

Bouguer gravity anomaly observed in the Murono mud volcano is negative gravity anomaly around -8.5 mGal, if Bouguer density is assumed to be 2400 kg/m^3. The area where conspicuous vertical movement was observed has lower gravity in the Murono mud volcano area, and it indicates that there would be low density layer in shallow depth. Here, we expect that this low density layer consists of muddy water, from geological and geophysical surveys around this area.

We have guessed that overpressure change of the low density layer caused the vertical movement observed at the surface. However, the observation by leveling should be continued for a while, in order to show a cause of the vertical movements. And, as additional observation, it will be better that we will carry out precise gravity observation on the bench mark periodically in order to trace mass movement due to overpressure change.

[Acknowledgment]
This study was carried out by the discretionary budget of the President of University of Toyama. In addition, Waseda University permitted us to carry out gravity survey and leveling on the premises in the Murono area and helped us for some observations. We are most grateful to University of Toyama and Waseda University.

Keywords: Mud volcano, Leveling, Gravity anomaly, Vertical movement

SSS34-P11 Room:Convention Hall Time:May 23 18:15-19:30

GPS observation in Mindanao, Philippines

Takahiro Ohkura[1*], Fumiaki Kimata[2], Takao Tabei[3], Teresito C. Bacolcol[4]

[1]AVL,Kyoto Univ., [2]Tono Research Institute of Earthquake Science, [3]Faculty of Science, Kochi University, [4]PHIVOLCS

The Philippine archipelago is currently wedged between two opposing subduction zones. The Eurasian plate is being subducted eastward along the Manila Trench on the western side while the Philippine Sea plate (PHS) is undergoing a westward subduction along the Philippine Trench on the eastern side. Between the trenches, the Philippine fault, a 1250-km-long, left-lateral strike-slip fault extends NNW parallel to the Philippine archipelago.

In order to mitigate disasters caused by earthquakes occurring along the trenches and the fault, a SATREPS project "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines" was started in 2009.

Under this project, we have started a GPS campaign observation in the eastern region of Mindanao island in order to assessing the potential for earthquakes along the Philippine fault and the Philippine trench in this region.

February 2010, we constructed 15 benchmarks in the region and started observation in March 2010. Each benchmark was occupied for 3-6 days with a dual frequency GPS receiver for 24 hours observation a day with a sampling interval of 30 second, and four campaigns were conducted until March 2013.

Obtained GPS data was processed with Bernese software (ver. 5.0) together with IGS stations data (BAKO in Indonesia, DARW in Australia, PIMO in Philippine, GUAM in Guam, and TCMS in Taiwan) to get daily coordinates in the ITRF2008 reference frame. Velocity of each site is calculated using a least square fitting in the ITRF 2008 and converted to velocities with respect to the Sunda block using the rotation pole estimated by Simon et al. (2007).

As a result in the northern part of the region, we could detected a left-lateral motion of the Philippine fault with 2 cm/year, which is almost the same amount of slip rate of the fault in Msabate Island detected by GPS observation.

In this region, paleoseismic trenches along the fault is also being conducted under the project.

With a view to assess the earthquake potential, we will continue GPS observation and integrate results of paleoseismic studies with present day crust movement.

Keywords: Philippine Trench, Philippine fault, GPS observation, Earthquake potential

SSS34-P12 Room:Convention Hall Time:May 23 18:15-19:30

Monitoring of fault creeping at south part of Metro Manila, Philippines

Katsumi Kurita[1*], KINUGASA, Yoshihiro[2], DEGUCHI, Tomonori[3], RIMANDO, Rolly E.[4], SASAGAWA, Tadashi[5], NON-AKA, Takashi[5]

[1]Tokyo Metropolitan College of Industrial Technology, [2]Association for the Development of Earthquake Prediction, [3]Nittetsu Mining Consultants Co.,Ltd., [4]Philippine Institute of Volcanology and Seismology, [5]PASCO

Metro Manila, in the Philippines, is the nation’s center of politics, economy, and culture. It has rapidly grown into an overcrowded mega city with an economically active population of at least 10 million. On the eastern portion of Metro Manila lies the active Marikina Valley fault system (MVFS). According to results of a trench survey (Nelson et al., 2000, Rimando et al. 2006), it has a potential for a M6-M7 earthquake occurring along the northern part of MVFS’ western segment. At the southern part of Metro Manila, while structures and pavements are damaged recently by ground deformation along the MVFS, no big earthquake whatever is involved. From a safety point of view of an urban area, it is important to monitor such the ground deformation.

In this study, monitoring of ground deformation was done through repeated leveling surveys and continuously through a creep measuring device installed across the MVFS’ creeping zone in the southern part of Metro Manila.

To monitor the slip rate, periodic leveling surveys across the creeping fault zone at six sites had been done since September 1999. Since there is little or no horizontal slip, the survey employed a simple leveling method using an electronic digital level and barcode leveling staff. Overall accuracy is estimated to be 2-3mm. Survey interval was initially every three months and later, every six months. At first, eight survey lines at four sites were set up but two survey lines at two locations were lost due to road repairs. Two new lines at other one site were set up on September 2012.

Three survey lines (VOS, JUA-A, JUA-B) show continuous creep dislocation. The average slip rate is 1.70cm/y. One survey line (NPC-A) shows no creep dislocation since the survey started in 1999 even though echelon cracks on the pavements are still visible. Two survey lines (NPC-B, NPC-C) and three survey lines (GRV-A, GRV-B GRV-C) show continuous creep dislocation until December 2007 and March 2010, respectively. The average slip rate of these five survey lines ranges from 1.07cm/y to 2.61cm/y. However, movement direction by creep was changed from East-up (West-down) to East-down (West-up) since December 2007 and March 2010.

To track detailed displacement changes at the creeping fault segments, continuous monitoring at NPC-B has been carried out since September 2008. The sampling interval is 3 hours. Until January 2009, the average slip rate gathered from this site is 0.01mm/day (3.65mm/y), the east side of the fault subsided (or the west side uplifted). Although the fluctuation of the displacement is +/-0.5mm, the fault creep appears to have stopped as of July 2009.

There are two hypotheses for the triggering mechanism of the continuous dislocation of the MVFS’ creeping zone segment. One is excessive withdrawal of groundwater due to rapid urban growth; the other is tectonic.

Several ground deformation anomalies were detected in Metro Manila through the InSAR time series analysis (Deguchi et al. 2011). Most of the vertical movements can be correlated with groundwater level changes. Some of the deformation are independent of the groundwater level changes in the areas surrounding MVFS. Therefore, the possibility that some of the deformation by creep are tectonic in nature cannot be denied.

Keywords: Active fault, Creep, Monitoring, Metro Manila

SSS34-P13 Room:Convention Hall Time:May 23 18:15-19:30

Strain Changes due to Groundwater Migration after Earthquakes Observed at Rokko-Takao Station

Atsushi Mukai[1*], Shigeaki Otsuka[2]

[1]Nara Sangyo University, [2]Kobe Gakuin University

The 2011 off the Pacific coast of Tohoku Earthquake on March 11, 2011 caused the step-like increase of groundwater discharge by 250ml/s as well as the step-like changes of strain by about 10^{-7} at Rokko-Takao station. In this study, we estimated the effect of groundwater migration and deformation in the fracture zone due to the great earthquakes such as the 2011 off the Pacific coast of Tohoku Earthquake by using the observational data of strain changes, groundwater discharge and groundwater level.

Rokko-Takao station is located in the emergency evacuation road for the Shin-Kobe tunnel, and crosses Manpukuji fault with the east-west strike. In the station, three components strainmeter (ST1:N81^{o}W, ST2:N39^{o}E, ST3:N21^{o}W), the groundwater discharge meter and the groundwater level meter were installed. The observation has been performed continuously with the sampling interval of 0.5 second.

The ordinary seepage rate of groundwater at the station is about 550ml/s. The groundwater discharge rate increased to 800ml/s just after the earthquake. After the earthquake, the groundwater discharge rate decreased to 300ml/s in a few days and recovered to the original rate in a few months. Strain steps due to the earthquake at the station showed the positive dilatation about 10^{-7}, which was calculated by using the fault model of Geographical Survey Institute. In general, positive dilatation causes decrease of groundwater discharge as well as decrease of pore pressure. However, the groundwater discharge at the station increased just after the earthquake. It is considered that the increase of groundwater discharge was caused by the outflow of groundwater through the groundwater channel formed by the seismic movement. As a result, the groundwater discharge decreased in a few months after the earthquake and the contraction of lateral strain was caused by the decrease of groundwater loading.

The maximum and the minimum principal strains of strain steps observed at the moment of the 2011 off the Pacific coast of Tohoku Earthquake were +0.9x10^{-7} and -3.8x10^{-7}, respectively, although the maximum and the minimum principal strains calculated by using the fault model were +1.7x10^{-7} and -0.9x10^{-7}, respectively. The observed and the calculated direction of the maximum principal strains were N31^{o}E and N54^{o}E, respectively. The observed principal strains of the strain steps have some discrepancies compared with those calculated theoretically by using the earthquake fault model as follows: the absolute values of principal strain observed are about two times larger than those calculated theoretically, and the directions of principal axes differ by about 20 degrees from those calculated theoretically. It is considered that these discrepancies were caused by the contraction of the fracture zone and the increase of pore pressure in the surrounding crust. If the fracture zone was contracted by 10^{-7} and the pore pressure increased by 9kPa, the calculated strain changes due to the earthquake could agree to the observed strain steps.

The strain changes were caused by the groundwater migration and pore pressure changes at the various earthquakes. In this study, we reported the effect of groundwater on strain changes due to the great earthquake over M7.

Keywords: strain change, groundwater discharge, Rokko-Takao station, 2011 off the Pacific coast of Tohoku Earthquake

SSS34-P14 Room:Convention Hall Time:May 23 18:15-19:30

Vertical ground deformation in the Omaezaki region obtained from the net adjustment of precise leveling survey

Kazutomo Takano[1*]

[1]GSI of Japan

This study reexamines the ground deformation by a leveling survey in the Omaezaki region. I reevaluate leveling data sets that were obtained from the Geospatial Information Authority of Japan (GSI). These data sets consist of elevation of permanent and temporary benchmarks calculated from the net adjustment of precise leveling survey. I am going to present the characteristic vertical ground deformation of the obtained result in this region.

Keywords: Leveling survey, Benchmark, Vertical crustal deformation, Tokai earthquake, Net adjustment, Cape Omaezaki

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS34-P15 Room:Convention Hall Time:May 23 18:15-19:30

The continuous stress, tilt, and pore-pressure observation at Mizunami Underground Research Laboratory

Yasuhiro Asai[1*], Hiroshi Ishii[1]

[1]TRIES, ADEP

Tono Research Institute of Earthquake Science, ADEP has constructed the crustal movement borehole observation site STG100 in February 2007, STG200 (March 2008), and STG300 (November 2012), respectively at Mizunami Underground Research Laboratory (MIU, JAEA). Up to the present , several variations in the crustal stresses, tilts associated with spring by digging of MIU.

We will present the details of these observation site and results of continuous stress, tilt observations with water pressure record.

Keywords: continous crustal stress observation, continous crustal tilt observation, borehole