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Thirteenth Japan-Taiwan International Workshop on Hydrological and Geochemical Research for Earthquake Prediction (Sep.2, 2014、Geological Survey of Japan, AIST)

No.	Time	
	10:00	TSUKUDA E. （Director of GSJ,AIST） Greeting
1	10:10	NAKAMURA,M.（FSUR) Activated very low frequency earthquakes by the slow slip events in the Ryukyu subduction zone
2	10:30	ANDO,M.(CIRENH) Seafloor geodetic observation of crustal deformation in the westernmost Okinawa trough
3	10:50	HU J.-C.(DGNTU) Monitoring of ground displacements in Metropolitan Taipei Basin by using high resolution X-band SAR interferometry
4	11:10	MURASE,M.(NUCHS) An Acceleration Event of Creeping Slip Detected by Precise Leveling Survey at the Central Part of the Longitudinal Valley Fault, Eastern Taiwan (2010-2013)
5	11:30	TSAI, M.-C.(CWB) The analysis of continuous GPS data and seismic activity in Taiwan area
6	11:50	KOMORI, S.(IEVG) Hydrothermal system at Tatun Volcano Group, Northern Taiwan, inferred from shallow crustal resistivity structures
	12:30	Photographing at the front of the main entrance of Geological Survey of Japan,AIST
	12:50	Lunch Meeting
7	14:10	LIAO, C.-W.(CWB) Tsunami Forecasting and Warning Procedure in Taiwan
8	14:30	JIANG,J.-S.(CWB) Seismological and Geophysical Observations for Earthquake Precursor Studies in Taiwan
9	14:50	LAI, W.-C.(DPRC) The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan (II)
10	15:10	KANO,Y.(DPRI) Array Observation Using Short-span Strainmeter
	15:30	休憩
11	15:50	HIGA,M.(FSUR) Depth-dependent coseismic groundwater level changes by seismic ground motion of the 1999 Chi-Chi earthquake, Taiwan
12	16:10	KINOSHITA,C.(DPRI) Change of permeability caused by 2011 Tohoku earthquake detected from pore pressure monitoring
13	16:30	KAWABATA, K.(KUM) Basic experiments for continuous monitoring of CH3 in the field by Mass spectrometer
14	16:50	KIMURA, H.(GSSSU) Microbial methane production and carbon-nitrogen cycles in subterranean environments associated with the accretionary prism in Southwest Japan
15	17:10	TANAKA,H.(GSSUT) Fluid Flux of Fault Zones - An Example from Arima Hot Spring
	17:30	DISCUSSION
	18:00	BANQUET

AIST: National Institute of Advanced Industrial Science and Technology
CIRENH: Center for Integrated Research and Education of Natural Hazards, Shizuoka Univ.
CWB:Central Weather Bureau, Taiwan,
DGNTU:Department of Geosciences, National Taiwan University,
DPRC: Disaster Prevention Research Center, National Cheng Kung University,
DPRI: Disaster Prevention Research Institute, Kyoto Univ.
FSUR: Faculty of Science, University of the Ryukyu,
GSJ: Geological Survey of Japan
GSSSU: Graduate School of Sciency, Shizuoka University,
GSSUT: Graduate School of Sciency, University of Tokyo,
IEVG:Institute of Earthquake and Volcano Geology, AIST,
KUM: the Kagoshima University Museum,
NUCHS: Nihon University College of Humanities and Sciences.

Activated very low frequency earthquakes by the slow slip events in the Ryukyu subduction zone

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The Ryukyu Trench, which is located at the northwestern boundary of the Philippine Sea plate, has had no known thrust earthquakes with a moment magnitude (Mw) greater than 8.0 in the last 300 years. Furthermore, only 5% of the moments accumulated by subduction, have been released as earthquakes during the latest 90 years (Peterson and Seno, 1984). Therefore, there is an assumption that the Ryukyu Trench is aseismic. Nevertheless, a large tsunami with a run-up height of up to 30 m struck Ishigaki Island and Miyako Island on April 24, 1771. The rupture source of the tsunami has been proposed as an Mw > 8.0 earthquake in the south Ryukyu Trench (Nakamura, 2009). Based on the dating of tsunami boulders, it has been estimated that such large tsunamis occur at intervals of approximately 150–400 years in the south Ryukyu arc (Araoka *et al*., 2013), whereas large paleo-tsunamis have not occurred for several thousand years in the central and northern Ryukyu areas (Goto *et al.*, 2014).

To address the discrepancy between the more recent low moment releases by earthquakes and the occurrence of large paleo-tsunamis in the Ryukyu Trench, we focus on the long-term activity of the very low frequency earthquakes (VLFEs), which are good indicators of the stress release in the shallow part of the plate interface. VLFEs have been detected along the Ryukyu Trench (Ando *et al.*, 2012), and because the centroid moment tensor solution of VLFEs shows the thrust-type, this suggests that VLFEs occur on the plate interface or at the accretionary prism.

We used broadband data from the F-net network of NIED along the Ryukyu Trench and in Kyusyu, and from the IRIS network (SSE and TATO). We applied two filters to all the raw broadband seismograms: a 0.02–0.05 Hz band-pass filter and a 1 Hz high-pass filter. After identification of the low-frequency events from the 0.02–0.05 Hz band-pass-filtered seismograms, the local and teleseismic events were removed. Then we picked the arrival time of the maximum amplitude of the surface wave of the VLFEs. Then, we determined the epicenter locations. The hypocenter depths are set to zero-kilometer.

VLFEs have occurred on the Ryukyu arc side within 100 km from the trench axis along the Ryukyu Trench. The number of observed VLFEs from January 1, 2002 to September 30, 2013 was 6670. The distribution of the VLFEs was inhomogeneous and could be divided into several clusters. The principal large clusters were distributed at 27.1°–29.0°N (Amami cluster), 25.5°–26.6°N (Okinawa cluster), and 122.1°–122.4°E (Yaeyama cluster). The activity of swarm-type VLFEs occurred frequently at intervals of 3–4 months at each cluster, and one swarm would last 2–7 days.

We found that the shallow VLFEs of the Yaeyama cluster are modulated by the repeating slow slip events which occur beneath south Ryukyu arc. The activity of the VLFEs increased to two or three times of its ordinary rate in 15 days after the onset of the slow slip events. The activation of the VLFEs could be generated by low stress change of approximately 0.02–20 kPa increase in Coulomb failure stress. This suggests that the strain in the plate interface where the VLFEs occur frequently would be released by small change in stress.

Moreover, the distribution of the VLFEs is complementally to the historical tsunami source area and locked area in the southwest Ryukyu Trench (Hsu et al., 2012). Continuous activity of VLFEs would release the stress patchily in the plate interface and give the constraint to the maximum size of large thrust earthquakes.

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Seafloor geodetic observation of crustal deformation in the westernmost Okinawa trough

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The seafloor positioning based on Kinematic GPS (KGPS) and acoustic ranging methods was applied to a site in the Okinawa trough, approximately 80 km east of Ilan, northeastern Taiwan. An array of three acoustic transponders forming a triangle in 2009 to 2011 and four transponders shaping a rhombus in 2010 to 2013 was positioned with respect to five onshore GPS sites using a shipboard interface between the GPS and acoustic ranging. The ship position was determined by KGPS; two-way travel times between the ship and the array were measured at 1000-6000 sites over the array. The array positions were estimated through two surveys in 2009, each survey in 2010, 2011 and 2012 and three surveys in 2013, using a method similar to a hypocenter determination technique. Three ocean bottom units were deployed in 2009 to 2011, while they were replaced with four seafloor units between 2010 and 2012. Fortunately, two transponders were active to cover the transition period of observation from the triangle to rhombus shapes of transponder arrangement. These two transponders made it possible to link all the survey results as a series of the campaign observation. Results from eight surveys thus obtained reveal that the horizontal and vertical velocities are 4 cm/y (southward) and 2 cm/y (uplift), respectively. This movement of the offshore Okinawa trough is close in direction to the GPS vectors at the GEONT stations on the islands of the Ryukyu ridge (Fig. 1). The consistency of the two observations implies that the rift of the Okinawa trough causes the southward migration of the Ryukyu ridge. Further long-term observation of seafloor geodetic survey is required to understand the mechanism of the rift of the Okinawa trough.

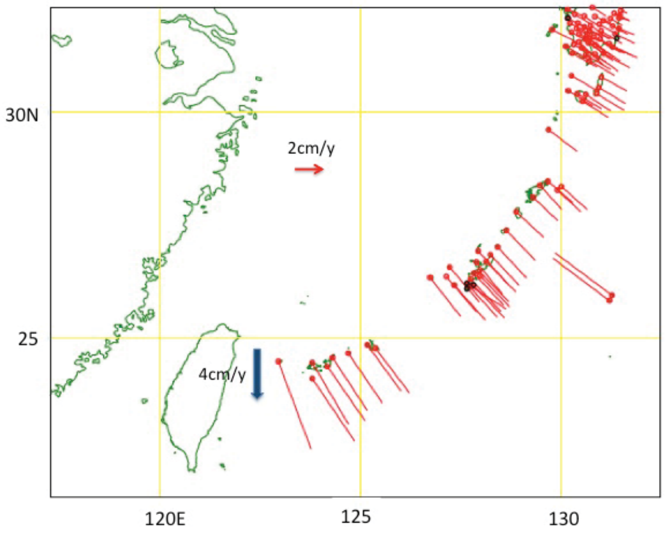

Fig.1 Horizontal GPS velocity vectors in the Ryukyu islands for the period of JAN 2006 to Jan 2011 with respect to the Amurian plate. The wide arrow depicts the velocity vector obtained from the seafloor geodetic survey for the period of 2009 to 2013.

Monitoring of ground displacements in Metropolitan Taipei Basin by using high resolution X-band SAR interferometry

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Located at the northern part of Taiwan, Taipei is the most densely populated city and the center of politic, economic, and culture of this island. North of the Taipei basin, the active Tatun volcano group with the eruptive potential to devastate the entire Taipei is only 15 km away from the capital Taipei. Furthermore, the active Shanchiao fault located in the western margin of Taipei basin. Therefore, it is not only an interesting scientific topic but also a strong social impact to better understand the assessment and mitigation of geological hazard in the metropolitan Taipei city. In this study, we use 12 high resolution X-band SAR images from the new generation COSMO-SkyMed (CSK) constellation for associating with leveling and GPS data to monitor surface deformation around the Shanchiao fault and the Tatun volcano group. The stripmap mode of CSK SAR images provides spatial resolution of 3 m x 3 m, which is one order of magnitude better than the previous available satellite SAR data. The higher resolution leads to an increase of the density of the measurable targets relative to those retrieved from medium resolution datasets (C- and L-band). Besides, the sensitivity of displacements is increased with shorter wavelengths, which enhance the capability of detecting very slow displacements rates. Furthermore, the more frequent revisit of the same Area of Interest (AOI) of the present X-band missions provides massive datasets to avoid the baseline limitation and temporal decorrelation to improve the temporal resolution of deformation in time series. After transferring the GPS vectors and leveling data to the LOS direction by referring to continuous GPS station BANC, the R square between PS velocities and GPS velocities is 0.96, which indicates the high reliability of our PSInSAR result. In addition, the well-fitting profiles between leveling data and PSInSAR result along two leveling routes both demonstrate that the significant deformation gradient mainly occurs along the Shanchiao fault. The severe land subsidence area is located in the western part of Taipei basin just next to the Shanchiao fault with a maximum of SRD rate of 30 mm/yr. However, the severe subsidence area, Wuku, is also one industrial area in Taipei which could be attributed to anthropogenic effect. In the future, we will use all available images to monitor the temporal and spatial variation in deformation to better understand the activity of the Shanchiao fault.

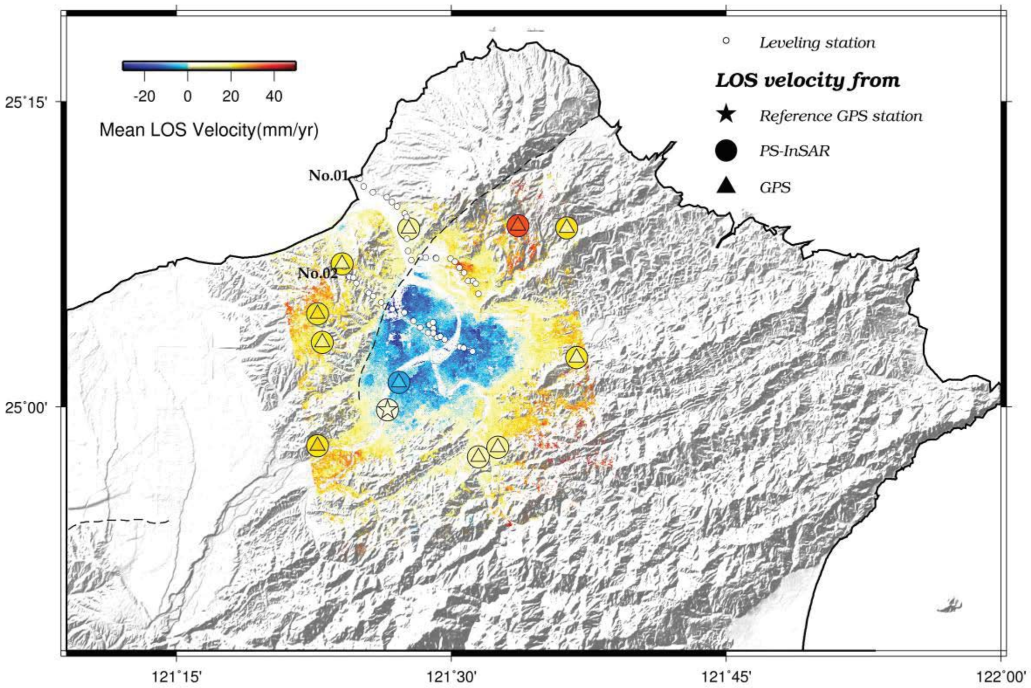

Fig.1 Mean LOS velocity field in Taipei area. Color-coded circle with triangle is LOS velocity projected from continuous GPS velocity. Small circles are the leveling routes.

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An Acceleration Event of Creeping Slip Detected by Precise Leveling Survey at the Central Part of the Longitudinal Valley Fault, Eastern Taiwan (2010-2013)

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Precise levelling surveys were conducted across the central Longitudinal Valley Fault, eastern Taiwan, to understand the deformation of the transition zone between the stable fault creep area and the locked area, which maybe correspond to an asperity. In order to investigate the surface relationship between the fault creep area and the geological condition of the transition zone, we established levelling routes in the Yuli, and Chike-san areas. The Yuli area forms the geological boundary of the Lichi Melange Formation, which is composed of chaotic mudstones containing numerous exotic blocks of various sizes and lithologies. Along the Yuli route, located on the Lichi Melange, an uplift rate of 30 mm/yr was detected during the period 2010–2013, suggesting that aseismic fault creep might be continuing with long-term stability. Along the Chike-san route, located on no Lichi Melange, a vertical deformation rate of 8 mm/yr, 40mm/yr, and 20mm/yr were detected in the period 2010–2011, 2011–2012, and 2012–2013, respectively (Fig.1).

The creep slip distribution was estimated by using a two-dimensional single-fault model proposed at Chike-san in the period 2012–2013. Large slip rates were estimated at 4~5 km of the fault plane (Fig.2). At the previous periods 2010–2011 and 2011–2012, relatively large slip rates were estimated at two parts of the fault plane—one at a depth of about 1.5 km and another at a depth of 4~5 km—. We believe that the acceleration event of creeping slip was continued at the depth of 4~5 km in the period 2012–2013. The northern limit of the stable creep area may be the Yuli area. The episodic creep event occurred in the transition zone between the stable fault creep area and the asperity area. The boundary between the stable creep area and the episodic creep area is consistent with the geological boundary of the Lichi Melange Formation.

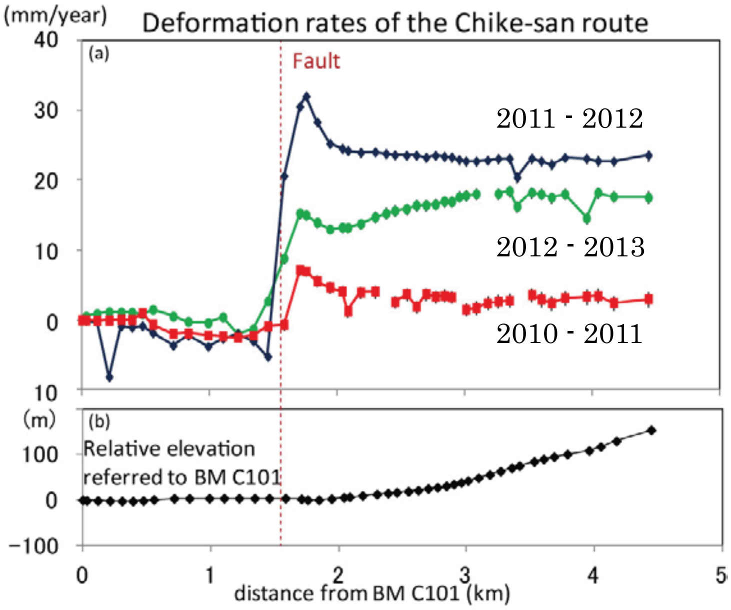

Fig. 1 (a): Vertical deformation of the Chike-san route detected by precise levelling. The reference point is BM C101 (BM C101 is the east end of the Chike-san route). Error bars denote the accumulated closing errors from BM C101. The dashed brown line denotes the location of LVF in the Chike-san route. (b): The route profile by the precise levelling survey. Relative elevations of the benchmarks in the Chike-san route are referred to BM C101.

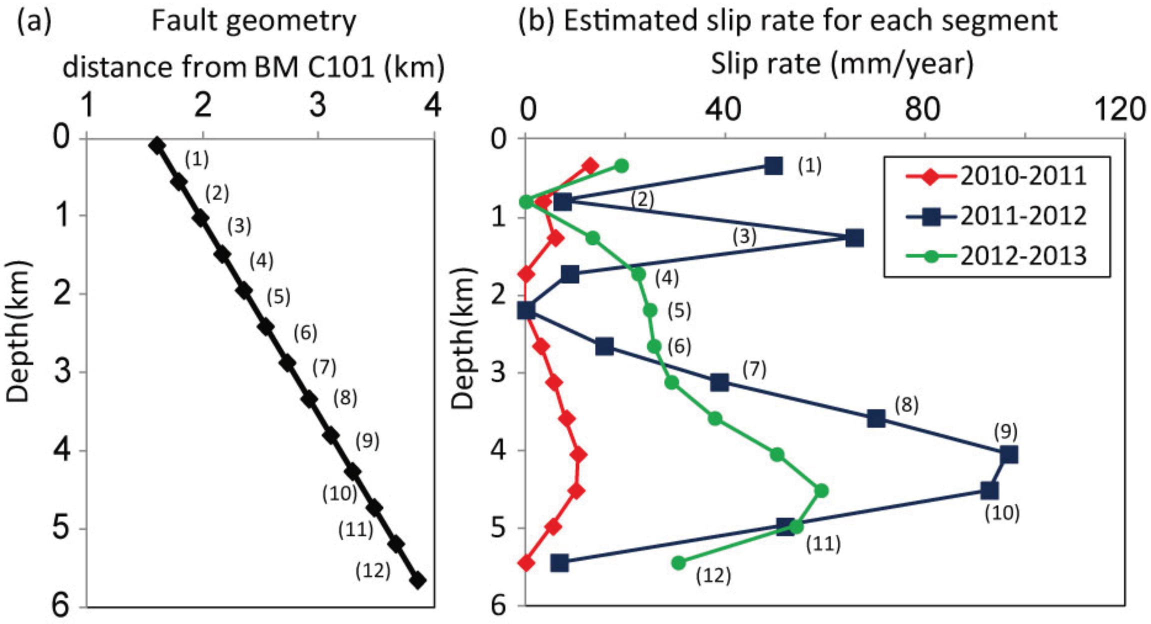

Fig. 2 (a) Depth profile of the 12 sub-faults. The black line denotes the geometry of the optimal fault model estimated by Murase et al. (2013). The diamonds denote the breakpoints of sub-faults. The sub-faults are numbered from 1 to 12. (b) Slip distribution of the 12 sub-faults for the period from 2012 to 2013. The green line denotes the estimated slip distribution of the 12 sub-fault in the period from 2012 to 2013. The slip distributions estimated by Murase et al. (2013) for the periods from 2010 to 2011 and from 2011 to 2012 are also shown. The red line denotes the estimated slip distribution of the 12 sub-faults in the period from 2010 to 2011, and the blue line denotes the estimated slip distribution of the 12 sub-fault in the period from 2011 to 2012.

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The analysis of continuous GPS data and seismic activity in Taiwan area

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Abstract

1. Introduction

Results from Global Positioning System (GPS) surveys provide key constraints to study active tectonics and geodynamics. Taiwan is situated in an active tectonic region where numerous thrust faults and folds were formed due to collision between the Luzon arc and Chinese continental margin. Lots of devastating earthquakes with magnitude more than 6 have occurred since 1900. The converging rate across the Taiwan arc-continent collision zone is about 80 mm/yr based on GPS measurements (Yu et al., 1997; Yu et al., 1999; Hsu et al, 2009). Approximately half of the plate convergence is accommodated in the fold and thrust belt of southwestern Taiwan and another half is taken up in the Longitudinal Valley and the Coastal Range in eastern Taiwan. The present geodetic characteristics indicate the complex tectonic structure in Taiwan area. Combining with the observed data of seismic activity, we hope to understand more about the possible earthquake potential area in Taiwan.

2. Tectonic setting

The active Taiwan mountain belt results from the oblique collision between the Luzon arc and the Chinese continental margin. The consequence of oblique collision makes the Taiwan region exhibit all stages of the collision process from south to north: pre-collisional rapid and distributed convergence, collision and suturing, and post-collisional collapse and extension (Lallemend and Tsien, 1997; Shyn et al., 2005). In the south, large anticlinal ridges and thrust faults deform the seafloors south of Taitung and Kaoshung. Between Tainan and Kaoshung are several active north–south trending folds and NE–SW striking right-lateral faults. In the eastern Taiwan, the active left-lateral oblique Longitudinal Valley fault crops out along the eastern flank of the entire valley and dips steeply beneath the Coastal Range. Major blind thrust faults accommodate most of the shortening across the Chiayi and Miaoli area. In contrast, two major thrust faults dominate the Taichung area. Rupture of the eastern one, the Chelungpu fault, produced the 1999 Chi-Chi earthquake. Active structures in the northern Taiwan accommodate extension above the Ryukyu subduction zone. Some active fault zones on both the northwestern and southern flanks of the Ilan plain are geomorphically evident.

3. GPS data and time series analysis

In the Taiwan area, there is a very dense GPS array composed of more than 300 continuous GPS (Cgps) stations. After 1999 Chi-chi earthquake (M_w = 7.6), there were more than 150 new Cpgs stations established, especially in Central Taiwan area. These continuous GPS stations have been operated by various agencies, including the Central Weather Bureau (CWB), Institute of Earth Sciences, Academia Sinica (IESAS), Central Geological Survey (CGS) and Ministry of the Interior (MOI) since 1998. For all continuous GPS data, we choose the time interval from 2007 to 2013 to avoid the influence of 1999 Chi-Chi earthquake. The time spans of more than half the amount of continuous GPS sites are all larger than 4 years. All the CGPS data are processed by GAMIT/GLOBK v.10.4 (Herring et al., 2010) with standard procedures.

The velocity at each continuous GPS site is calculated from position time series through a simple model which removes outliers and systematic errors in the data. This model is composed of a linear rate, annual and semi-annual periodic motions, coseismic displacements, post-seismic relaxation (exponential or logarithmic decay), and offsets caused by instrument changes (Nikolaidis, 2002).

$$\begin{aligned} y(t_i) \;=\; & a + bt_i + c\sin(2\pi t_i) + d\cos(2\pi t_i) + e\sin(4\pi t_i) + f\cos(4\pi t_i) \\ & + \sum_{j=1}^{n_g} g_j H(t_i - T_{gj}) + \sum_{j=1}^{n_h} h_j H(t_i - T_{hj}) t_i \\ & + \sum_{j=1}^{n_k} k_j exp(-(t_i - T_{kj})/\tau_j) H(t_i - T_{kj}) + v_i \end{aligned}$$

4. GPS Velocity Field

The horizontal velocity fields results from time series analysis in the Taiwan area from 2007 to 2013 presents the significant velocity field change from east to west. Stations in the eastern mountain area (western margin of Central Range, Hualien-Taitung area) show W-WNW directed motions with rates of 60-83 mm/yr. Across the Longitudinal Valley, there are about 20 mm/yr velocities decreased. In Central Range region, the smaller velocities are observed about 43-54 mm/yr with a west directed motion. It keeps decrease to 37-43 mm/yr at Chiayi-Tainan area, and start to do the counterclockwise rotation with a velocity about 52-57 mm/yr in Kaoshung-Pingtung area. For the north-eastern Taiwan, the clockwise rotation with average rete of 15-27 mm/yr is observed in Ilan area, and only about 0-5 mm/yr in Taipei area, that indicates the obvious crustal deformation here. At Taichung area, velocity keep decreases form 1999 Chi-chi earthquake to 2006, the clear post-seismic deformation can be observed. The average horizontal velocity field is about 27-30 mm/yr for now.

5. Seismicity

Taiwan is located at the plate boundary with earthquakes frequently. Plate tectonics can be directly described by the distribution of seismic activity in space. In northern Taiwan, most earthquakes happened along Ryukyu subduction zone where the Philippine Sea plate northward plunge beneath of Eurasian Plate. In the contrast, the Eurasian Plate plunge beneath of Philippine Sea plate at Pingtung area which is also lots earthquake happened. Usually those earthquakes are with depth larger than 30 km, most of the shallow seismic activity is on land. At western Taiwan, high seismic activity surrounding the Peikang Basement High is prominent, lots of disastrous 7 earthquakes happened at the deformation frontal thrust zone. t the eastern Taiwan, the Longitudinal

Valley is an east-dipping seismic suture zone that separates two different tectonic regions. On the left-hand side, shallow earthquakes and normal fault-type focal mechanism were found in the Central Range region. But on the right-hand side, most events occurred in the Philippine Sea Plate (PSP) were of the thrust-type. There are tremors happened frequently at Hualien – Nashan area, it may worth us to discuss and think about relationship between the tremors and large earthquakes.

6. Summary

The dense CGPS network and active seismicity can provide us rich data to understand more about the relationship of geodesy, seismology, and tectonic structure in Taiwan. In this study, we separate Taiwan to 7 regions depends on tectonic setting and seismicity, combing the geodetic data, the result shows the potential of precursor at Hualien area. GPS time series presents very different characteristics form north to south there, and the significant periodic motion and semi-annual periodic signal are observed in east and vertical component for the stations on the hanging wall of Meilun Fault respectively. Consider with the adequate data time interval and site characteristics, HUAL and DOFU could be the index station for precursor monitoring.

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Hydrothermal system at Tatun Volcano Group, Northern Taiwan, inferred from shallow crustal resistivity structures

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This study will propose the improved conceptual model for the hydrothermal system at Tatun Volcano Group, located in the northern tip of Taiwan (Fig 1). In the study, AMT (audio-magnetotellurics) surveys were conducted to reveal the spatial distribution of resistivity, which has a great sensitivity to fluid connectivity, temperature, salinity, liquid saturation, and hydrothermal alteration. By combining the obtained resistivity structure with the other geophysical and geochemical evidence, the following hydrothermal system is inferred (Fig 2 and 3). Beneath Mt. Chishinshan, hydrothermal fluids are supplied from a deeper part; that is supported by clustered burst events from Konstantinou et al. (2007)’s seismological study and a pressure source estimated from Murase et al. (2013)’s geodetic study. Vapors are maintained in a low to relatively-low resistivity region (5-20 Ωm), covered by a clay-rich cap represented by an upper extremely-low resistivity layer (less than 3 Ωm). Portion of the vapors develop the Siao-you-keng fumarolic area. Their mixing with shallow groundwater forms the shallow flow system of hydrothermal fluids at Matsao area, represented by the region less than 10 Ωm; that is supported by Ohsawa et al.(2013) ’s geochemical study. The fumarolic gas of Da-you-keng area comes from a southern vapor-dominant region beneath Cing-tiang-gang; that is supported by another clustered burst events and pressure source (Konstantinou et al., 2007; Murase et al., 2013), and simple mixing between magmatic vapor and meteoric fluids inferred by Ohba et al. (2010) ’s geochemical study. Horizontally extending vapor-bearing regions also suggest that there may be still a possibility of phreatic eruptions, as occurred in c.a. 6,000 years ago (Belousov et al., 2008). The above conceptual model could provide clues to detect the precursors of future volcanic hazards.

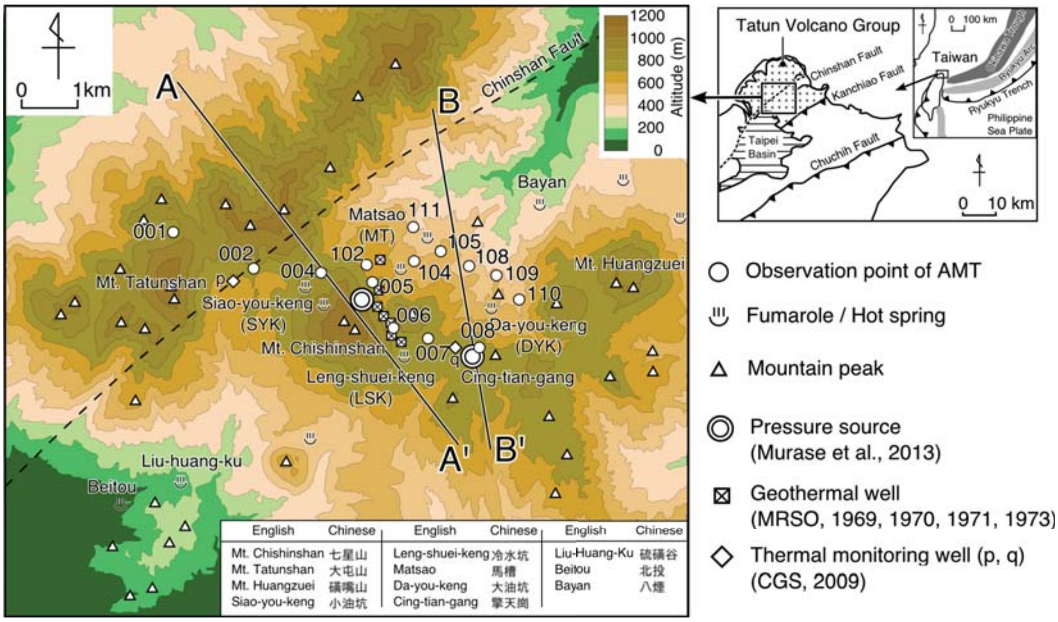

Fig.1 Location of Tatun Volcano Group, northern Taiwan. Open circles represent the observation points of AMT.

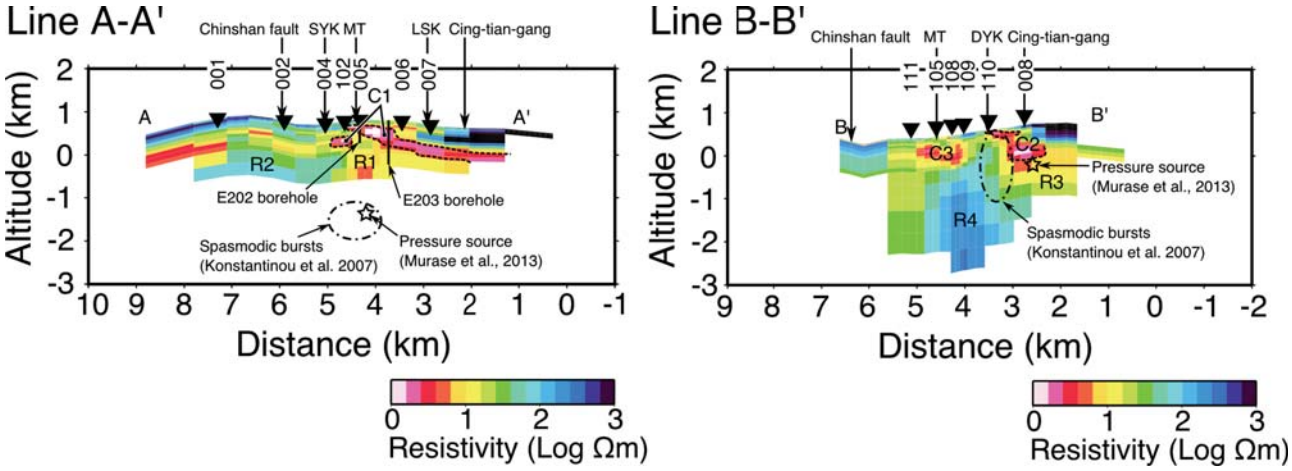

Fig.2 Resistivity structures along Line A-A' and B-B', after removal of less sensitivity part. The location of pressure sources (Murase et al., 2013) and spasmodic bursts (Konstantinou et al. 2007) are shown by the stars and ellipses in the structure along Line A-A' and Line B-B', respectively.

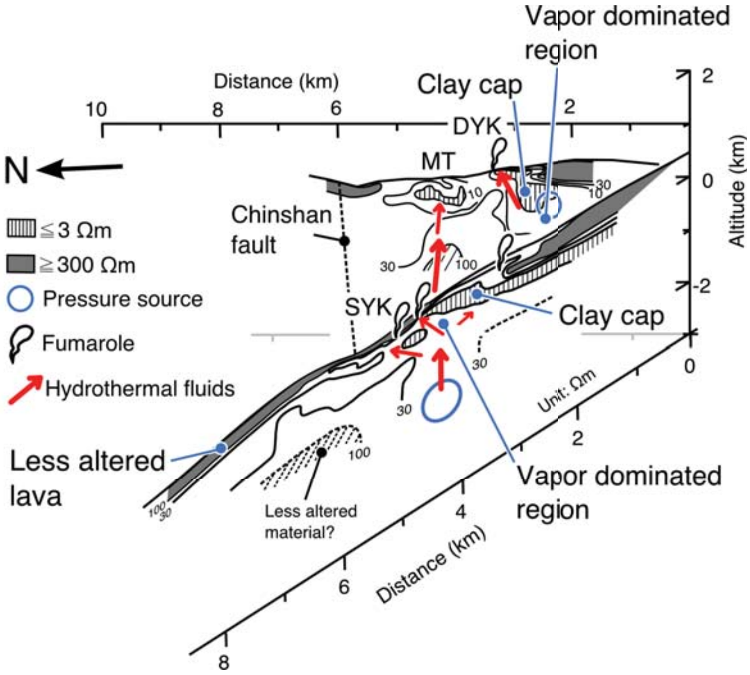

Fig.3 Conceptual model for the hydrothermal system of Tatun Volcano Group.
It was inferred by the interpretation of the resistivity structure and other geochemical and geophysical evidences.

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Tsunami Forecasting and Warning Procedure in Taiwan

Che-Wei Liao, Nai-Chi Hsiao, Po-Yu Lin, Wen-Chi Hsiao and Chiao-Ying Lee

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Abstract

The issuing of tsunami warning on coastal areas of Taiwan is mainly governed by Central Weather Bureau (CWB). Due to the limitation of the monitoring capability for global earthquakes, the tsunami warning procedure has been commonly treated under two headings: distant tsunami and local tsunami. For distant tsunami threat, CWB receives earthquake parameters from Pacific Tsunami Warning Center (PTWC), and evaluates the influences of tsunami to Taiwan instantly. In the view of local tsunami, this system is integrated with the earthquake rapid reporting system of CWB, with the assessment of numerical modeling results, timely tsunami information can be provided for the coastal areas of Taiwan. For the latest developments, the integral ability for Taiwan against far-field and local tsunamis has been improved. As regards regional tsunamis, which occur away from hundreds of kilometer to one thousand, the present mechanism availability does not able to give an effective prevention. Therefore, the enhancements on the cooperation with neighboring countries, such as unobstructed connections between Japan and Philippines, are in great demand for the prevention of Taiwan against regional tsunamis.

Introduction

Taiwan is located on the western circum-Pacific seismic belt, and has experienced numerous destructive earthquakes with severe casualties and property losses. Although in comparison to seismic hazards, tsunami hazards in Taiwan are relatively rare in historical records. However, from the teachings of 2004 Sumatra tsunami and 2011 Tohoku tsunami, the tsunami hazards could be devastating despite their infrequent nature. Therefore, it is necessary to establish an effective tsunami warning system in Taiwan.

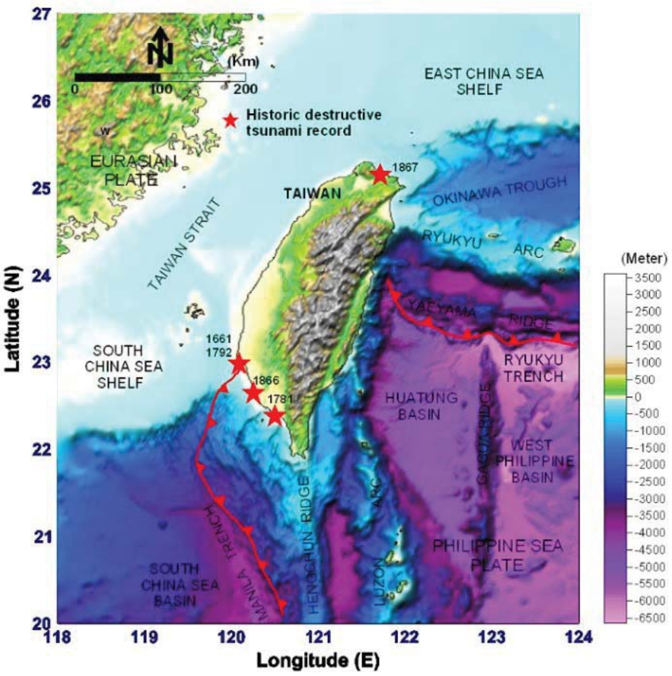

Fig.1 Locations of the disastrous tsunamis probably affected Taiwan area before.

Tsunami warning system

Although the effects of destructive distant tsunamis on Taiwan were unobvious, such as 1960 Chile, 1964 Alaska, and 2011 Japan tsunamis. CWB can receive distant tsunami warning report from the PTWC while a Pacific-wide tsunami taking place in the Pacific rim. Once CWB receives tsunami information from PTWC, the crew on duty will confirm parameters and trigger the computation of tsunami estimation. The core of computation is based on Cornell Multi-grid Coupled Tsunami Model (COMCOT), which is used to simulate tsunami propagation, including its arrival time, affected area and maximum wave height. When a shallow earthquake with great magnitude occurs near Taiwan, tsunami could attack coastal areas within tens of minutes, thus it is important to develop tsunami warning system which can estimate and issue threat level quickly. The task of tsunami monitoring is integrated with the Taiwan Rapid Earthquake Information Release System (TREIRS). By means of the high efficiency on rapid focal parameters determination of TREIRS, with the assessment of numerical modeling results, timely tsunami information can be provided for the sake of tsunami hazard mitigation.

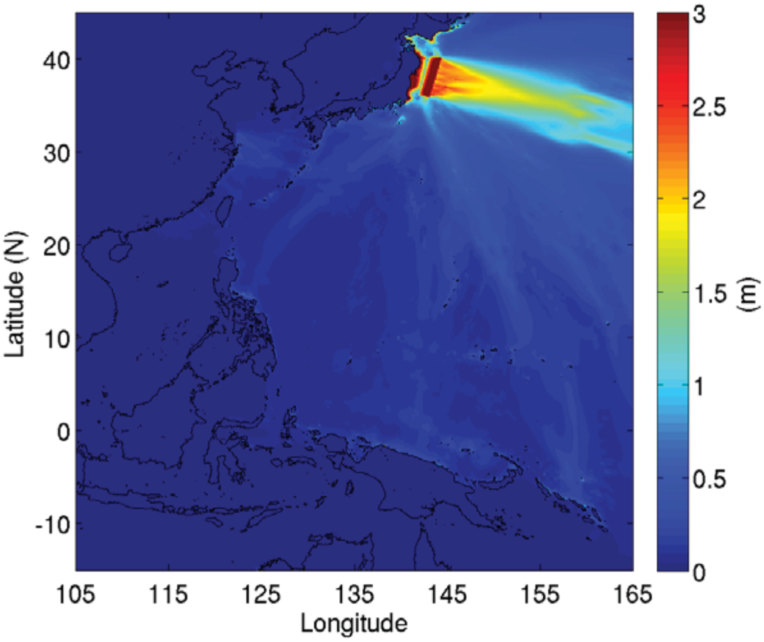

Fig.2 Simulated maximum wave height of 2011 Tohoku tsunami.

Operation procedure of issue

According to the regulation, when a shallow earthquake with magnitude greater than 6.0 occurs offshore Taiwan, the watchword ‘watch for the abnormal sea level variation‘ will be posted on the earthquake report as reference. And a tsunami warning report will be dispatched formally while the magnitude of earthquake is greater than 7.0. By means of the forecast wave amplitude, areas affected are classified into 4 levels: less than 1 meter, 1 ~ 3 meters, 3 ~ 6 meters and larger than 6 meters. Each has a distinct meaning relating to local emergency response. On the other hand, according to the possibility of tsunami threat, surrounding seabed topography, and administrative division, CWB divided coastal areas into six warning regions. Finally, CWB will issue the warning message to some mitigation agencies with mobile phone short message or email, and dispatch formally the warning report to public.

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Seismological and Geophysical Observations for Earthquake Precursors Studies in Taiwan

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This research about earthquake prediction is mainly in the monitoring and analyses of earthquake precursors, broadly collect the precursor phenomenon before strong earthquake happened, included change of the groundwater level, crustal deformation and variations of the ionospheric total electron content (TEC). The Global Positioning System (GPS) has broad applications in geosciences. Recently scientists study variations of the ionospheric total electron content (TEC) to search anomalies associated with strong earthquakes. The Central Weather Bureau (CWB) has set up hundreds of GPS receivers to monitor land deformation and seismicity. This project is to combine the groundwater and GPS to monitor pre-earthquake anomalies and to also foresee the epicenter in Taiwan.

For observing the precursors of the earthquakes, CWB cooperated with Water Resources Agency to establish the real-time transmission system in 6 groundwater observation stations with sampling rate of 1 sample per second. The seismicity in eastern Taiwan is more activity than other regions of Taiwan. The groundwater station, Hualien, in eastern Taiwan has more opportunity than other stations to detect the precursors.

For investigating the relationship between seismic activities and crustal deformation in Taiwan, the Central Weather Bureau (CWB) started to set up the permanent stations for the Global Positioning System (GPS) network since 1993. The GPS has become one of the most important geodetic tools for studying crustal deformation. From 1993 to 2000, the CWB had set up 17 permanent GPS stations. To better investigate the relationship between post-seismic activities following the Chi-Chi earthquake in Taiwan and any crustal deformations, the CWB established 133 GPS stations from 2001 to 2005. Now, the CWB GPS Network includes a total amount of 150 stations with multifunction monitoring system and variable station spacing which depends on seismotectonic activity and population density, less than 50 km on average. The continuously recording GPS data collected from the CWB GPS Network were adopted to reveal the crustal deformation of Taiwan. Analyzing the time series of GPS stations in Taiwan processed by the Bernese software, the average root-mean-square (rms) values of residuals for all stations after removing the coseismic offsets, periodic variations and linear trend. GPS velocities for the stations varied from 3.2 mm/yr to 69.8 mm/yr in azimuths ranging from 33.5° to 335.6°. The area with maximum strain rate is along Coastal Range (0.24μstrain/yr). The Ilan plain, strain rate estimated from GPS velocities is 0.10μstrain/yr. Through utilizing the satellite positioning technique, each station can provide precise global coordinate for its antenna position that can be used to monitor the horizontal and vertical crustal movement at the site. It can serve as important information about the deforming crust caused by related plate motion in this area. Further studies can be explored in the fields related to seismic activities, stress accumulation and release, and the physical properties of earthquakes.

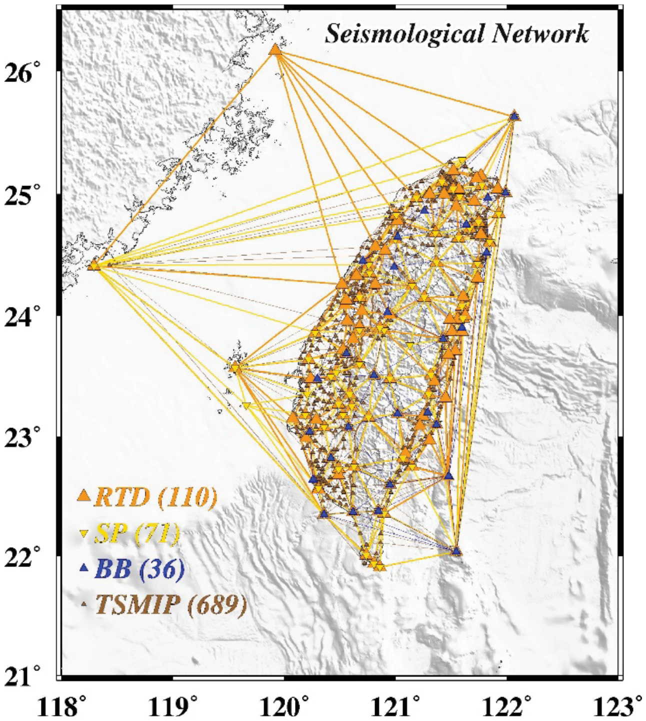

Fig.1 The location distribution of CWB seismological stations.

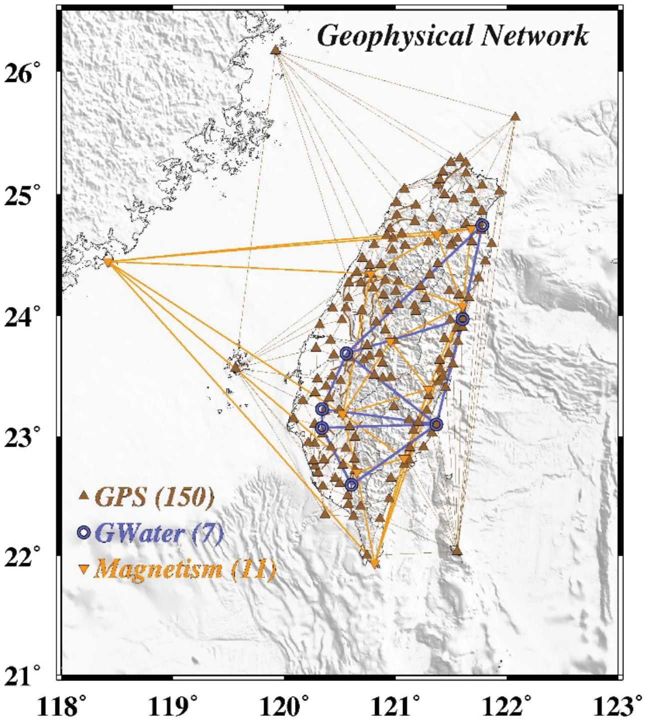

Fig.2 The location distribution of CWB geophysical stations.

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The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan (II)

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The different response by various natural stimuli and processes (tidal force, barometric loading, ground shaking and crustal strain) were used as the elements of the hydraulic information in the earthquake induced groundwater level changes. Using the ocean tidal force to act as naturally recurring stimuli to provide a sufficiently varied distribution of excitations in time and space, and represented the hydro-geological changes responses to the earthquake processes. The purposes of this study are to analyze the recently observation results of the earthquake induced tidal deviation of groundwater level in observation wells around Hualien city, eastern Taiwan. The analysis of the tidal responses and the atmospheric pressure responses also will be used to estimate the mechanical properties of the aquifer. Comparison the observation between the sea level and the groundwater level changes in the each event, offers the opportunity to discussion the possible mechanism of the hydrologic response to earthquake. Curiously pre-seismic groundwater level changes in the pattern of tidal deviation occurred repeatedly in several local seismic events nearby the Hualien City. Poroelastic model been used to act as the simulation tool to fit to the pre-seismic groundwater level changes. The results shows groundwater preseismic change could be simulated by a recharge or discharge at a fault zone with poroelastic model. The numerical results could support our conceptual model with a permeable fault zone between sea loading and groundwater responses. Our numerical model provides some information for the preseismic mechanism but more investigations are required.

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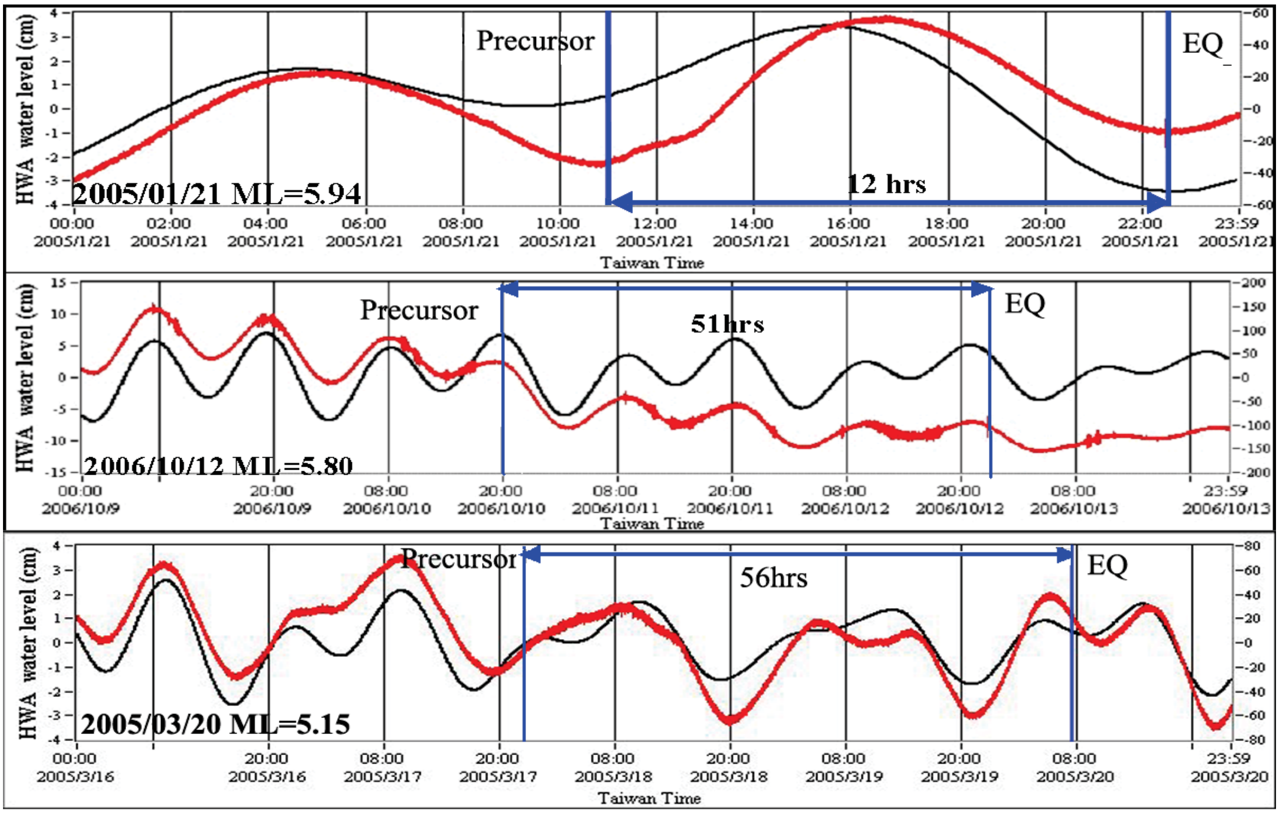
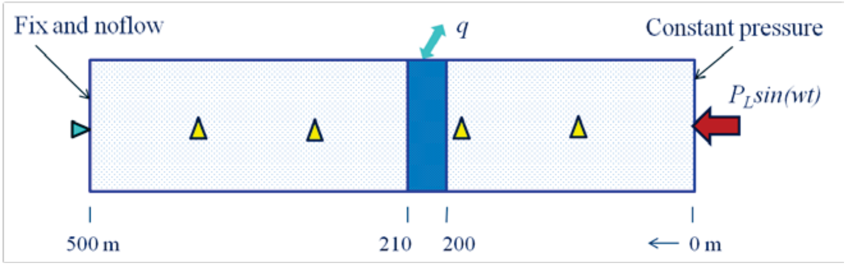
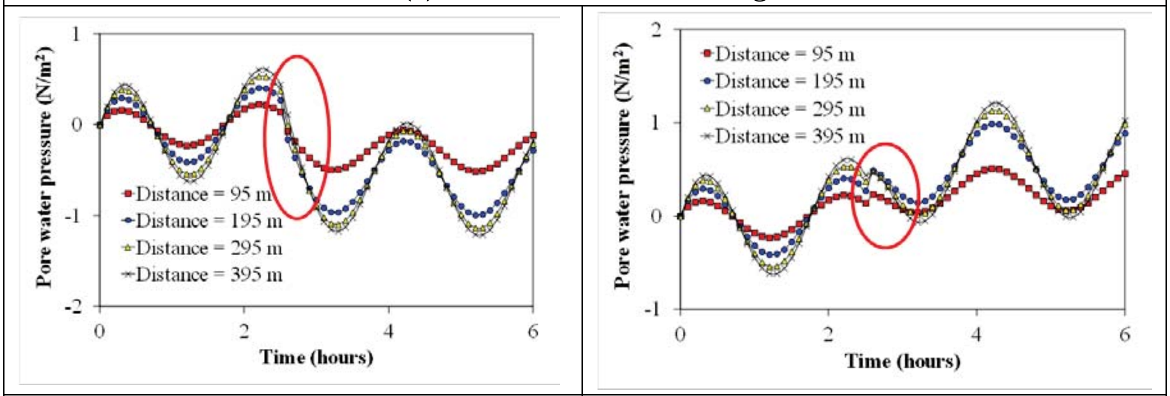


Fig.1 Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien observation well, Hulien City.



(a) Poroelastic model setting



(b) Discharge Cases

(c) Recharge Cases

Fig.2 Poroelastic modeling results for discharge and recharge conditions in fault zones close to Hulien observation well, Hulien City.

Array Observation Using Short-span Strainmeter

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Crustal deformations have been observed associated with deep low-frequency tremors occurring below the Kii peninsula and Shikoku. Strain measurements by an extensometer at Kishu operated by DPRI, for example, show that the sources with epicentral distance of 30 - 40 km causes strain changes of 10^{-9} to 10^{-8} occurring within several days. Although the traditional extensometer observations can detect these strain changes, it is difficult to make detailed analyses because of the limited number of stations.

We designed a short-span extensometer with 1.5 m-long standard measure. Strong coupling of the instrument to the ground is important for stable observations, so three anchor bolts fixed to the base of the instrument are cemented into a 50-cm-deep hole. Each component (standard measure, displacement sensor, etc.) has the same design with conventional strainmeter. The only difference is that length standard is much shorter. Adoption of the same parts with conventional strainmeter allow us to efficiently develop and maintain new strainmeter.

We installed three component shot-span strainmeter at Nakaheji (NHJ), Kii peninsula, Japan. We observed crustal deformation associated with deep low-frequency tremors by the short-span extensometer installed at Nakaheji. One example is the transient strain change detected at Nakaheji during the activity of low frequency earthquakes on March, 2013. AIST (2013) provided a fault model for this event (Mw5.5), which corresponds to latter half of the strain change. We made a forward estimation of a fault model corresponds to the strain change prior to the Mw5.5 event.

We are preparing another sites for installation of the strainmeter around the western Kii Peninsla to construct array of strainemters. The array observation contributes to improve the detection capability of crustal deformation by eliminating noise caused by weather disturbance and to have better understanding of slow slip events such as slip distribution.

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Depth-dependent coseismic groundwater level changes by seismic ground motion of the 1999 Chi-Chi earthquake, Taiwan

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The coseismic groundwater level changes (Cw) have been often reported (e.g. Montgomery and Manga, 2003; Koizumi, 2013). Two main causes of the Cw are crustal deformation (static strain change, vertical displacement, etc.), and seismic ground motion, which causes dynamic volumetric strain change, liquefaction, hydraulic conductivity change, etc.(Lee et al., 2002; Lai et al., 2004; Wang et al., 2001). The static volumetric strain change has been proposed as one of the main factor of the water level change. Many reports have showed a good relationship between the Cw and the coseismic static volumetric strain changes. However, such a good relationships has not always been found. Although the seismic ground motion sometimes affects the Cw more effectively (e.g. Koizumi, 2013; Lee et al, 2002), the quantitative relationship between the Cw and seismic ground motion has not been estimated yet.

Chi-Chi earthquake (Mw7.6) occurred in central Taiwan at 1:47 (local time) on September 21, 1999. The earthquake was the largest event that occurred recently in the inland of Taiwan. Since both networks of strong motion seismometer (Lee et al, 1999) and water level monitoring system (Water Resources Bureau, 1999) were distributed densely around the source fault of the Chi-Chi earthquake, good data of the seismic ground motion and the Cw caused by the Chi-Chi earthquake were obtained.

Wang et al.(2003) analyzed the Cw by the 1999 Chi-Chi earthquake with the seismic ground motion and they interpreted it was caused by the liquefaction at the shallow aquifer in the alluvial plain. However, since they analyzed the Cw at all the observation wells together, the difference in hydrogeological conditions of each aquifer (e.g., aquifer confinedness, hydraulic conductivity,) was ignored. Since the generation of liquefaction depends not only on seismic ground motion but on the hydrogeological conditions. Therefore the contribution of the hydrogeological conditions to the Cw should be evaluated. Therefore we investigated the relationship among the Cw, seismic ground motion and hydrological conditions.

First we classified the observed aquifers under five layers; Layer1, Layer2-1, Layer2-2, Layer3, and Layer4, which are based on Hsu et al.(2000). The observation wells where the Cw increased and decreased were 135 and 9, respectively. We used the data of the wells in the alluvial plain where the Cw increased because those wells are considered to have the same mechanism to produce the Cw. We investigated the relationship between spectral response of the seismic wave and the Cw . The responses of Cw against the ground motions at the frequency of 1 Hz (high-frequency) and 0.1 Hz (low-frequency) were computed, respectively. We computed the spectral responses of acceleration, velocity, and displacement for vertical, horizontal, and three components from acceleration waveform data, respectively. Finally, we computed the correlation coefficient between the spectral response and the Cw in each of the layers (Table 1).

The result shows that the response for each frequency is different. The correlation efficient between the Cw and the spectral response at the high-frequency (1 Hz) is larger in the layer 1, which is the unconfined aquifer. However, the correlation at low-frequency (0.1 Hz) is larger in the confined aquifers (layer2-1, 2-2, 3 and 4). This means that the Cw or the pore pressure changes would be affected by the low-frequency seismic ground motion more effectively in the confined aquifers. Since the seismic ground motion by the Chi-Chi earthquake was dominant with low frequency component (0.17～0.037Hz), the low-frequency seismic ground motion would have strongly affected the Cw in the confined aquifer. On the other hand, in the case of the unconfined aquifer, the pore pressure change by the low-frequency seismic ground motion would have diffused to surrounding layers. Thus, high-frequency seismic ground motion would strongly affect the Cw in the unconfined aquifer.

horizontal spectral response

	Acceleration		**velocity**		**displacement**	
layer	**0.1Hz**	**1Hz**	**0.1Hz**	**1Hz**	**0.1Hz**	**1Hz**
1	0.42	**0.54**	0.52	**0.57**	0.25	**0.62**
2-1	**0.41**	0.36	**0.68**	0.38	**0.61**	0.43
2-2	**0.43**	0.38	**0.71**	0.40	**0.63**	0.45
3	**0.26**	0.16	**0.62**	0.15	**0.57**	0.22
4	**0.53**	0.32	**0.80**	0.34	**0.87**	0.41
total	**0.19**	0.15	**0.47**	0.18	**0.45**	0.23

Table.1 Correlation coefficient between the horizontal spectral response and the Cw at 0.1Hz and 1Hz.

Change of permeability caused by 2011 Tohoku earthquake detected from pore pressure monitoring

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Previous studies have investigated the relationship between water and earthquakes via pore pressure, groundwater and seawater. Earthquake-induced changes in groundwater level have been widely observed (e.g., Manga et al., 2012).

We have monitored pore and atmospheric pressures at the Kamioka mine in Gifu Prefecture, central Japan since 2005 to study relationship between groundwater and earthquake. Pore pressure decreased after the 2011 Tohoku earthquake (M9.0) occurred on 11 March 2011, which may be attributed to expansion of the crust by the earthquake or a permeability increase. The epicentral distance is 520 km. To evaluate rock permeability changes, we analyzed the Earth tide response of pore pressure before and after the earthquake. Pore pressure fluctuates associated with the meteorological effects, Earth tides and crustal deformation. We assumed that tidal response of pore pressure is constant if there is no change of aquifer conditions. We compared the tidal response before and after the earthquake. We extracted amplitude and phase lag of M_2 and O_1 constituents from pore pressure by tidal analysis program, BAYTAP-G (Tamura et al., 1991). These amplitudes decreased and phases changed after the earthquake. This is consistent with pore pressure decreases. We estimated the hydraulic diffusivity from change of tidal response using poroelastic theory and diffusion equation. If we assume that the poroelastic coefficient is constant, the hydraulic diffusivity increased from 9.5 to 18.5 m^2/s at the time of the Tohoku earthquake. We also analyzed data before and after the Noto Hanto Earthquake (M6.9) which occurred in the northwestern part of Ishikawa Prefecture, central Japan on 25 March, 2007. The epicentral distance of the Noto Hanto Earthquake from our observation site is 112 km. No hydraulic diffusivity change is detected. The causes of the hydraulic diffusivity change are potentially related to a static and/or dynamic stress change. In order to discuss the difference in hydraulic diffusivity change between the Tohoku and Noto Hanto earthquakes, we analyzed other earthquakes to relate the hydraulic diffusivity changes, and the amount of static and dynamic strain changes.

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Basic experiments for continuous monitoring of CH3 in the field by Mass spectrometer

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3. OYO Corporation
4. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo

Continuous gas monitoring in the field is important issue for various purposes such as for heat trapping gas monitoring, poisonous gas monitoring and scientific objective. In order to analyze the gas in the field, small-sized gas analyzer using mass spectrometer have been developed in our group (Our web page http://growdas.com gives detailed explanation about the machine). In the field, identifying the location of the emitted gas is needed. To detect gas-emission in distant places from the analyzer, we made basic laboratory experiments using long tube and methane gas.

We made holes in attaching 25 m long tube and injected methane gas from the holes. The signal of the methane gas and the interval of time between injection and appearance of the signal were measured. We adjust the gases for experiment controlling total volume and methane percentage. In this presentation, we introduce the results of the experiment. We also used numerical method and compared the results with experimental results.

Microbial methane production and carbon-nitrogen cycles in subterranean environments associated with the accretionary prism in Southwest Japan

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3. PRESTO, Japan Science and Technology Agency (JST), Japan.

The accretionary prism situated along the Pacific side of Southwest Japan is traceable laterally for some 1,800 km. It forms thick sediment that accretes onto the non-subducting tectonic plate at a convergent plate boundary. The sediment is composed mainly of non- to weakly metamorphosed sequences of sandstone, shale, alternating beds of both, and local associations of chert and greenstone. The materials are derived from marine sediment scraped from the subducting oceanic crust. Therefore, they are rich in complex organic matter. The sediment contains layers of water-bearing permeable sandstone and no water-bearing impermeable shale. Groundwater is mainly recharged by rainfall infiltrating into outcrops or faults. The water flows down through the permeable sandstone and is reserved in a deep aquifer. In addition to the groundwater, it has been reported that dissolved natural gas (mainly methane) is present in the deep aquifer associated with the accretionary prism.

To understand methane production pathways in the deep aquifer associated with the accretionary prism, samples of groundwater and natural gas were collected from 14 deep wells in Shizuoka Prefecture, Japan. A series of geochemical and microbiological studies of the groundwater and the natural gas were performed. Stable carbon isotopic analysis of methane in the natural gas and dissolved inorganic carbon in groundwater suggested that the methane was mainly derived from biogenic process. Bacterial and archaeal 16S rRNA gene analyses revealed the dominance of H_2-producing fermentative bacteria and H_2-using methanogens in the groundwater. Anaerobic incubations using groundwater amended with organic substrates suggested high potentials of H_2 and CO_2 generation by fermentative bacteria and methame production by H_2-using methanogens. Furthermore, anaerobic incubations using groundwater amended with nitrite or nitrate were performed. Consequnetly, a high potential of microbial denitrification was also shown.

These results suggested that pass and ongonig syntrophic biodegradation of organic compounds by H_2-producing fermentative bacteria and H_2-using methanogens contributes to the methane production in deep aquifer assciated with the accretionary prism. In addition to the methane production, microbial denitrification, which means N_2 production, using methane and/or organic matters as electron donors seems to be present in the deep aquifer.

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Fluid flux of fault zones -an example from Arima hot spring

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This manuscript presents results of physical and chemical examinations of fluids of hot springs at Arima area. There are several high-T hot spring sources, which are flown out continuously to the surface in Arima area. After hot spring drillings at the 1940 to 1950's, constant amounts and quality of these hot springs are maintained by branch of coal government office of Kobe City. Many researches have been done for the hot springs so far, including surface geology, shallow underground structure, source of fluids and fluids paths. Fluid paths are inferred to be fracture zones of particular fault zones by results of geological survey and resistivity analysis. It is important to recognize these kinds of fluids as "fault zone fluids", since identification whether monitored fluids flow through fault zone or not is important issue to examine the crustal activities from the chemical and isotopic compositions of the fluids. It is also well known that fluids from Arima hot springs show specific isotopic compositions, which are inferred to be very deep origin. In this presentation, we discuss about quantity of flux of deep source fluids of Arima hot spring which is important issue to answer the question why we need to observe the fluids for crustal activities and where? and compare the results between this and previous studies.