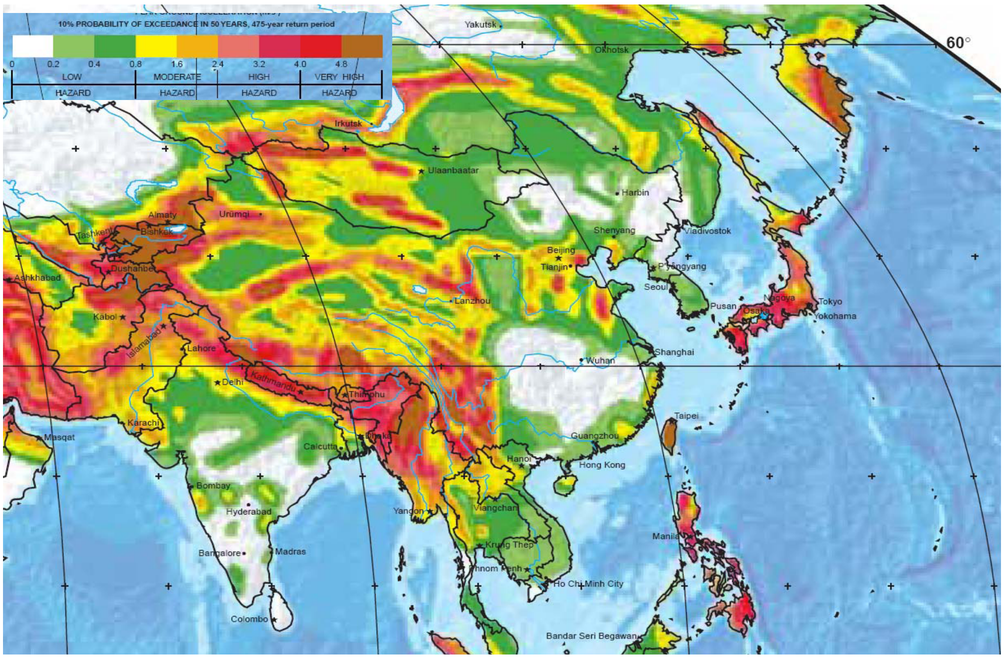
14th Taiwan - Japan International Workshop on Hydrological and Geochemical Research for Earthquake Prediction

September 15, 2015

National Cheng Kung University, Tainan, Taiwan

-PROCEEDINGS-



Edited by

Chjeng-Lun Shieh, Naoji Koizumi and Norio Matsumoto

DPRC Disaster Prevention Research Center
National Cheng Kung University
No.1,Ta-Hsueh Rd. Tainan 701, Taiwan

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2016

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Organizer:

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Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology

Sponsor：

Earth Science Research Promotion Center, National Sciences Council

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Preface

Both of the NCKU-DPRC (the Disaster Prevention Research Center, National Cheng Kung University, Taiwan) and the IG-GSJ (Institute of Geoscience, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology) were agree to pursue scientific and technical cooperation about hydrological and geochemical research for earthquake prediction in Taiwan in February 2002.

Follow the cooperation agreement, DPRC-NCKU and IG-GSJ intend to carry out cooperative research activities on (1) Investigation of groundwater anomalies associated with the earthquake in Taiwan; (2) Analysis of the natural groundwater level changes in correlation to the geotectonic and meteorological activities; (3) Improving methodologies in monitoring and studying the groundwater anomalies with respect to geotectonic activities and/or other aspect as well; (4) Compiling the future periodically-monitored information of groundwater chemical and physical properties, and geotectonic anomalies; and(5) Analysis of the groundwater anomalies as earthquake precursors.

The 1st International Workshop on Hydrological and Geochemical Research for Earthquake prediction had held on Sep. 24, 2002 at GSJ, AIST, Tsukuba, Japan. The workshop had good beginning to promote the research cooperation between Japan and Taiwan. The main purpose of the workshop this time is proceeded to collaborate, and provide an opportunity to share the precious experience with other researchers. In total, seventeen papers will be presented in this workshop.

Although the earthquake prediction is a hard scientific challenge in the century, keeping on study and making any kind of approach are the better way to contribute earthquake hazard mitigation. We hope that this workshop will offer the good ideas and experiences for related work. In view of these sincerely cooperation, we absolute believe that will help us to preserve more safety for our life.

September, 2015

Chjeng-Lun Shieh and Naoji Koizumi

14th Taiwan - Japan International Workshop on Hydrological and Geochemical Research for Earthquake Prediction, Workshop Program (September 15, 2015)

【Sep.15 】Place: International Conference Room, National Cheng Kung University

Place	Time	Program		
International Conference Room	08:30~09:00	Registration		
	09:00~09:15	Opening Ceremony		
	Time	Speaker	Title	Coordinator
	09:15~09:40	Masataka Ando	The recurrence of large tsunamis and seismic coupling along the the weakly-coupled southern Ryukyu subduction zone	Ruey-Juin Rau
	09:40~10:05	Min-Chien Tsai	Preliminary study of GPS baseline variation and its implication to seismic activity	
	10:05~10:30	Mamoru Nakamura	Tidal triggering of shallow very-low-frequency earthquakes in the Ryukyu Trench	
	10:30~10:55	Yuzo Ishikawa	Redetermination of hypocenters in and around Taiwan in early 20 century	
	10:55~11:10	Coffee Break		
	11:10~11:35	Naoji Koizumi	Groundwater pressure change and crustal deformation before and after the 2007 and 2014 eruptions of Mt.Ontake	Masataka Ando
	11:35~12:00	Kuo-Fong Ma	Investigation on fluid migration seismicity in association with fault zone damage: case study for 1999 M7.6 Chi-Chi, Taiwan, earthquake	
	12:00~12:25	Ryoya Ikuta	Monitoring of seismic velocity using ACROSS around Nojima fault rupture zone and Tokai subduction zone in Japan	
	12:25~13:30	Lunch Time		
	13:30~13:55	Hiroyuki Kimura	Regional variation of CH4 and N2 production processes in deep aquifers associated with the accretionary prism in Southwest Japan	Naoji Koizumi
	13:55~14:20	Vivek Walia	Earthquake Precursory Studies Using Continuous Soil Gas Monitoring Data in Taiwan: An Overview	
	14:20~14:45	Fumiaki Tsunomori	Radon concentration distribution of groundwater around Tachikawa fault	

	14:45~15:10	M. C. Tom Kuo	Anomalous decrease in groundwater radon and dissolved-gases before the Taiwan and Japan earthquakes	
	15:10~15:30	Coffee Break		
	15:30~15:55	Chihiro Kinoshita	The change of rock permeability induced by Tohoku earthquake	Wen-Chi Lai
	15:55~16:20	Ching-Yi Liu	Temporal changes of earthquake-related groundwater level	
	16:20~16:45	Keiji Asano	Ascension of Fluid from Mud Volcanoes Distributed along Anticline and Fault Zones	
	16:45~17:10	Wen-Chi Lai	The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan	

Content

The recurrence of large tsunamis and seismic coupling along the weakly-coupled southern Ryukyu subduction zone

Masataka Ando*[1] and Ryoya Ikuta[2,1]

1. Center for Natural Hazards of Integrated Education and Research, Shizuoka University, Shizuoka, Japan
2. Department of Geosciences, Faculty of Science, Shizuoka University, Shizuoka, Japan

The Ryukyu subduction zone is characterized by a well-developed extensional arc, suggesting that the upper and lower plates are coupled weakly with the infrequent occurrence of large earthquakes (Figure 1). The seismic coupling, (the ratio between the observed seismic moment release rate and the rate calculated from plate tectonic velocities), along the Ryukyu subduction was estimated very as low as 0.05 [Peterson and Seno, 1984] or 0 [Scholz and Campos, 2012]. Moreover, the absolute strain rate in the Ryukyus is less than 3 to 5 x 10^{-8} yr^{-1}. On the other hand, the absolute strain rate in Honshu and Kyushu along the Nankai trough, where large earthquakes (Mw>=8.0) repeatedly occur, is 1 to 3×10^{-7} yr^{-1}, 1/2 to 1 order of magnitude larger than that along the Ryukyus (Figure 2).

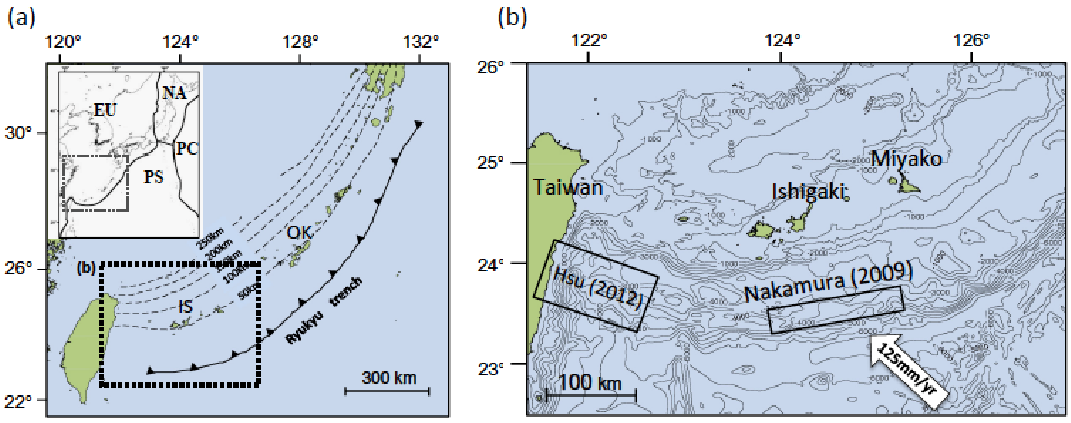

Figure 1. (a) The depth of the seismic plane of the Philippine Sea slab (solid contours with the unit of km). IS: Ishigaki Island and OK: Okinawa Island. The insert depicts plate tectonics setting of Ryukyus. **(b)** Fault segments along the western Ryukyu: the 1771 earthquake according to Nakamura (2009) and the segment on Taiwan defined by Hsu et al. (2012). The thick and white arrow indicates the plate convergence at 12.5 cm/yr with a direction along the western Ryukyu islands (Heki and Kataoka, 2008).

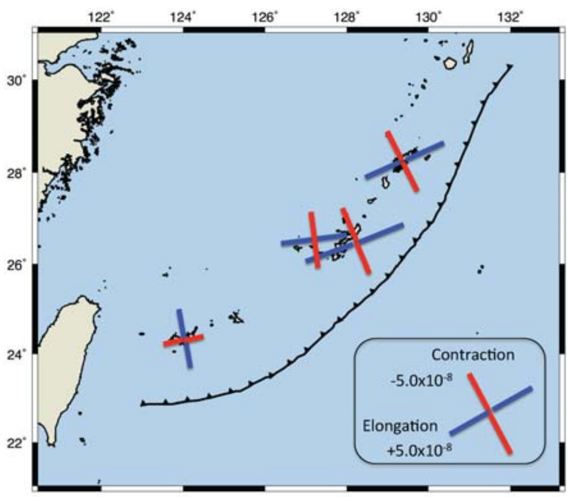

Figure 2. Contraction and elongation strain rate (y^{-1}) axes at the four areas, Amami, East Okinawa, West Okinawa and Yaeyama along the Ryukyu trench (from east to west) on the basis of GNSS GEONET data (Jan 1, 2010 to Dec. 31, 2010). The local rigid rotation effects along the Ryukyu arc were removed from the velocity vectors in the islands before the estimation of strain axes.

Despite the extensional stress regime, a large tsunami (Mt = 8.5) struck the coasts of Ishigaki, Miyako, and surrounding islands along the western Ryukyu Trench on 24 April 1771. North of the source area of this event, we found deposits of four paleotsunamis (including the 1771 event) that occurred during the last 1,800 years on Ishigaki Island (Figure 3). Assuming that these four tsunamis were generated on a fault along the western Ryukyu subduction zone (Nakamura, 2009), the seismic coupling ratio between the upper and lower plates can be estimated to be 25 % (Ando et al., 2015). The results of this study indicate that strain can be accumulated similarly along the other segments of the Ryukyu trench and released to generate significant tsunamis in the future.

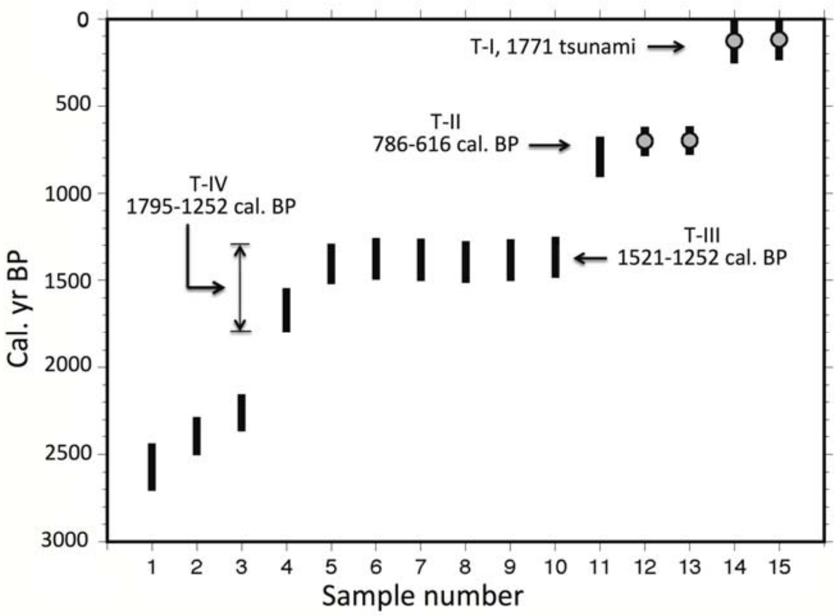

Figure 3. ^{14}C dates (cal. yr BP) of four tsunami s, T-I, T-II, T-III and T-IV. Radiocarbon samples were obtained from deposits in an excavation trench on Ishigaki Island. The error bars with gray circles show reliable dates for the articulated marine bivalves that were transported and buried alive by tsunamis of T-I and T-II.

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Preliminary study of GPS baseline variation and its implication to seismic activity

Tsai, Min-Chien*[1]

1. Seismological Center, Central Weather Bureau, Taiwan

Abstract

1. Introduction

Taiwan is situated in an active tectonic region with numerous thrust faults and folds due to on-going collision between the Luzon arc and Chinese continental margin. Numerous devastating earthquakes with magnitudes greater than 6 have occurred since 1900. The oblique convergence of the Eurasian and Philippine Sea Plates started at the beginning of Late Miocene period (Ho, 1976; Barrier and Angelier, 1986; Huang et al., 2006). The Global Positioning System (GPS) has become an efficient tool for studying active tectonics and geodynamics (Dixon, 1991; Hager et al., 1991; Feigl et al., 1993). Utilizing satellite positioning techniques each station can provide precise global coordinates for its antenna position which can be used to monitor the horizontal and vertical crustal movements at the site. There are more than 400 continuous GPS (cGPS) stations in Taiwan area now. The dense cGPS network provide a wealth of cGPS data for study. The present geodetic characteristics indicate the complex tectonic structure in Taiwan area. Combining with the observed baseline variation result and 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. Data collection and processing

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 2014 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.

4. GPS velocity field in Taiwan

Results from Global Positioning System (GPS) surveys provide key constraints to study active tectonics and geodynamics. 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 velocities in western Taiwan generally show a fan-shaped pattern, consistent with the maximum compression tectonic stress direction. In northern Taiwan the velocity vectors reveal clockwise rotation, indicating the on-going extensional deformation related to the back-arc extension of the Okinawa Trough. In southern Taiwan, the horizontal velocity increases from about 40 mm/yr in the Chia-Nan area to 55 mm/yr in the Kao-Ping area with a counterclockwise rotation.

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. 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 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. Baseline variation

We divided Taiwan into four areas which are with numerous faults and active seismicity. There are Hualien-Taitung area, southwestern area, Chelungpu fault zone area, and north Taiwan area. There total 76 baselines are using in this study, some of them are more than 50 km. In order to understand the precision of baseline data, the formalism proposed by Savage and Prescott (1973) is utilized to describe the precision of the epoch GPS measurements as a function of baseline length:

$$\sigma_L = \sqrt{a^2 + b^2 \,\mathrm{ı}\, L^2}$$

Where σ_L is the standard deviation, L is the baseline length, and b are constant and length dependent source of error, respectively. The result indicates the precision is much worse in vertical component. Therefore, the baseline estimation we only use north and east two components. The observation of baseline from daily solution helps us understand more and the fault activity, area tectonic structure, and possible precursor signal. Compare the slope of baseline time series with the velocity field obtain by time series analysis, noise analysis, and common mode error correction, the result quite consistent. Furthermore, the baseline slope variation may give a suggestion of local strain field is changed.

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 4 regions depends on tectonic setting and seismicity, combing the geodetic data, the result shows the potential of precursor at Hualien area. GPS time series and the baseline variation all present 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, the Hualien area should be an index region for precursor monitoring.

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Tidal triggering of shallow very-low-frequency earthquakes in the Ryukyu Trench

Mamoru Nakamura*[1] and Keito Kakazu[1]

1. Faculty of Science, University of the Ryukyus, Japan

Slow earthquakes, which occur around the source fault of large subduction zone earthquakes, are occasionally triggered by tidal stress. The tidal response is affected by the high pore-pressure fluid or change in material property in the plate interface [*Ide, 2010; Royer et al., 2015*].

We focus on the tidal response of shallow very-low-frequency earthquakes (VLFEs), which occur in the shallow part of the Ryukyu Trench, and showed that the activity of VLFEs responds to ocean tide loading and is controlled by the thickness of the subducted sediment.

We used information from the epicenter catalog, the epicenter determination procedure of which is the same as that described by *Nakamura and Sunagawa* [*2015*]. The epicenters in the catalog are determined using the arrival time of the maximum amplitude of the surface wave using a 0.02–0.05-Hz band-pass-filtered waveform of the broadband seismograms (F-net and IRIS) around the Ryukyu Trench. The period analyzed extended from January 2002 to December 2014. The minimum magnitude of the events used for the analysis was 3.4, which was determined from the magnitude–frequency relationship [*Nakamura and Sunagawa, 2015*]. Overall, 6595 events were used for the analysis.

First we computed Fourier analysis of VLFEs in the central and southwestern Ryukyu. If the VLFE occurred in the area, we considered a sequence of delta functions located at all hypocentral times. Next we computed the tidal sensitivity and phase lag between the occurrence of VLFEs and the ocean tide for each point, separated at intervals of 0.2°, for both the east–west and north–south directions along the Ryukyu Trench. We then predicted the fault normal stress (FNS) and updip shear stress (UDSS) and their time derivatives dFNS and dUDSS on the plate interface and compared them with the excess value (N_{ex}) of the VLFEs [*Cochran et al., 2004*]. The stress components at a depth of 15 km were computed by using point-source surface loading in the homogeneous half space [*Malvern, 1969*]. The stress components were predicted using Earth tide strain [*Matsumoto et al., 2001*; *Lambert et al., 2009*] and ocean tide [*Malvern, 1969; Matsumoto et al., 2000*].

The results of computed Fourier analysis of VLFEs show that strong peaks in the spectra, corresponding to the lunar semi-diurnal tide (M2), luni-solar declinational tide (K1), and principal lunar declinational tide (O1), can be seen in central Ryukyu, whereas these peaks are obscured by background noise in southwestern Ryukyu.

The result of distribution of tidal sensitivity shows that the sensitivity and phase change gradually from northeast to southwest along the Ryukyu Trench. High sensitivity (0.20–0.42) is evident at central Ryukyu Trench, but the sensitivity is < 0.2 at southwestern Ryukyu Trench.

The N_{ex} in the FNS ranges from 0.22 to 0.28 at central Ryukyu and from 0.04 to 0.11 at southwestern Ryukyu. The N_{ex} in the UDSS ranges from 0.17 to 0.22 at central Ryukyu and from

0.04 to 0.11 at southwestern Ryukyu.

The comparison of N_{ex} with stress components shows that the VLFEs are activated by the thrust-encouraging shear stress or maximum extensional normal stress of the ocean tide corresponding to the low-tide period. The tidal sensitivity is highest in the central portion of the Ryukyu Trench, where the thin sediment layer is subducting and an accretionary prism is not developed, whereas it is lowest in the southwestern portion of the Ryukyu Trench, where a thick sediment layer exists and an accretionary prism is well developed. This suggests that differences in the sediment–rock properties of the overriding plate, which cause lateral heterogeneity in the extremely high pore-fluid pressure in the plate interface, control the sensitivity of the shallow very-low-frequency earthquakes to ocean tides.

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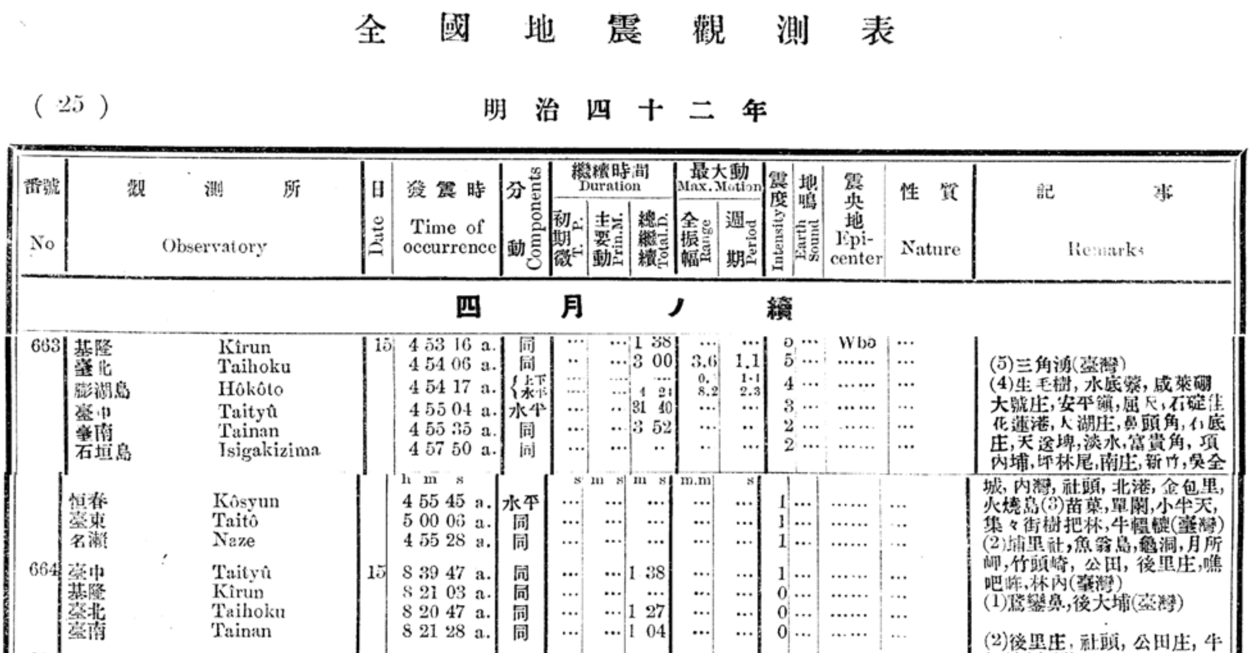
Redetermination of hypocenters in and around Taiwan in early 20 century

Yuzo Ishikawa

AIST, Geological Survey of Japan, Active Fault and Earthquake Research Center

The earthquake annual reports including P wave arrival times were published by the Central Meteorological Observatory in early 20 century. These arrival times from 1907 to 1910 were inputted. The events of which P wave arrival times were more than 2 were selected for the re-determinating hypocenters. Most of the old station locations were measured by GPS using WGS84 coordinate system and some stations were estimated by Google Earth. HYPOSAT （Schweitzer,1997,2001） was used to determine hypocenters and the velocity structure AK135(Kennett et al.,1995) was adopted.



全　國　地　震　観　測　表

(25)　　明　治　四　十　二　年

番號 No	観測所	Observatory	日 Date	發震時 Time of occurrence	分動 Components	繼續時間 Duration 初期微動 T.P.	主要動 Prin.M.	總繼續 Total D.	最大動 Max. Motion 全振幅 Range	週期 Period	震度 Intensity	地鳴 Earth Sound	震央地 Epi-center	性質 Nature
				四月ノ續										
663	基隆	Kîrun	15	4 53 16 a.	同	…	…	1 38	…	…	5	…	Wbo	…
	臺北	Taihoku		4 54 06 a.	同	..	…	3 00	3.6	1.1	5	…	……	…
	澎湖島	Hôkôto		4 54 17 a.	{上下 水平	…	…	4 21	0. 8.2	1·1 2.3	4	…	……	…
	臺中	Taityû		4 55 04 a.	水平	…	..	31 40	…	…	3	…	……	…
	臺南	Tainan		4 55 35 a.	同	…	..	3 52	…	..	2	…	……	…
	石垣島	Isigakizima		4 57 50 a.	同	…	…	..	..	…	2	…	……	…
				h m s		s	m s	m s	m.m	s				
	恒春	Kôsyun		4 55 45 a.	水平	…	…	…	…	…	1	…	……	…
	臺東	Taitô		5 00 06 a.	同	…	…	…	…	…	1	…	……	…
	名瀬	Naze		4 55 28 a.	同	…	…	…	…	…	1	…	……	…
664	臺中	Taityû	15	8 39 47 a.	同	…	…	1 38	…	…	1	…	……	…
	基隆	Kîrun		8 21 03 a.	同	…	…	…	…	…	0	…	……	…
	臺北	Taihoku		8 20 47 a.	同	…	…	1 27	…	…	0	…	……	…
	臺南	Tainan		8 21 28 a.	同	…	…	1 04	…	…	0	…	……	…

記事 Remarks

(5)三角湧(臺灣)
(4)生毛樹，水底寮，咸菜硼大號庄，安平鎭，屈尺，石碇庄花蓮港，大湖庄，鼻頭角，石底庄，天送埤，淡水，富貴角，項內埔，坪林尾，南庄，新竹，吳全城，內灣，社頭，北港，金包里，火燒島(3)苗栗，罩蘭，小半天，集々街樹把林，牛轀轆(臺灣)
(2)埔里社，魚翁島，龜洞，月所岬，竹頭崎，公田，後里庄，噍吧哖，林內(臺灣)
(1)鷺鷥鼻，後大埔(臺灣)

(2)後里庄，社頭，公田庄，牛

Fig.1 This is the sample of the seismic observation table of Meiji 42 (1907).　The events occurred in May 15, 1907 were shown by events No. 663. This event most hardly shook Taipei.

The biggest earthquake in this period was April 12, 1910 in the east China Sea.　It was only one event of which hypocenter was determined by ISC-GEM.　The second biggest was occurred on Apr. 14 1909 beneath Taipei.　The hypocenter parameter was report by Utsu, but not by ISC-GEM version 2.　The hypocenter parameters are shown the followed.

Utsu	1908 01 11 03:34:00(UT)	23.00	121.10	10km	M6.7
This study	1908 01 11 03:35:20	25.7182	119.3747	0	
Utsu	1908 07 01 07:28:00(UT)	24.00	122.00	60km	M6.1
Utsu	1909 04 14 19:53:00(UT)	25.00	122.50	100km	M7.2
This study	19:54	24.91	122.44	207km	
This study	1909 05 23 10:43:44	25.5455	119.2412	13.9km	

This study	1909 09 29 13:49:48	23.9557	119.8888	0km	
This study	1909 10 03 01:38:54	23.5083	121.8552	25.6km	
Utsu	1909 11 21 07:36:00	25.50	122.00	10lm	M7.0
This study	07:36:19	25.0400	122.4193	14.9	
Utsu	1910 01 06 19:55:00	24.00	123.00	60km	M6.2
This study	19:55:35	27.2147	119.9935	72.7	
This study	1910 01 12 14:49:36	23.4395	122.7930	0	
This study	1910 01 20 17:27:17	24.0710	122.3640	61.6	
This study	1910 02 20 14:12:47	24.9268	121.0757	0	
This study	1910 03 25 18:37:27	24.0052	121.4363	2.4	
This study	1910 04 02 07:22:49	23.5612	121.4732	32.6km	
ISC-GEM	1910 04 12 00:22:24(UT)	25.9110	123.9730	235km	M8.1
Utsu		25.00	123.00	200km	M7.6
This study		25.911N	123.973E	235	
This study	1910 06 17 05:28:22	23.2695	121.5620	21.3km	(M6.8)
This study	1910 09 01 00:44:46	22.3110	120.2097	121km	
This study	1910 09 01 14:21:25	24.7925	121.0880	0km	
This study	1910 09 01 15:22:00	25.1677	122.5067	44.2km	
This study	1910 11 11 09:05:41	24.7837	123.0738	40.5km	
This study	1910 11 14 07:34:17	23.9787	120.2048	23.7km	(M7.0)
This study	1910 11 29 02:26:34	22.0800	120.1702	93.6km	
This study	1910 12 01 21:42:17	24.0305	120.9068	50km	

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Groundwater pressure change and crustal deformation before and after the 2007 and 2014 eruptions of Mt.Ontake

Naoji Koizumi*[1] ,Tsutomu Sato[1], Yuichi Kitagawa[1] and Tadafumi Ochi[1]
1.AIST, Geological Survey of Japan, Institute of Earthquake and Volcano Geology

Geological Survey of Japan, AIST started groundwater observation at the Ohtaki observatory (GOT) in 1998. GOT is about 10km southeast of the top of Mt.Ontake (Fig.1). At GOT we measure groundwater pressure in a sealed well. Since the groundwater pressure at GOT has tidal changes caused by the earth tides, we estimated the volumetric strain sensitivity of the groundwater pressure, which is 1.5-2 mm/nstrain, where the groundwater pressure is expressed as water head and "nstrain" means 10^{-9} strain. Since the resolution of the pressure gage at GOT is 2 mm, that of the volumetric strain converted from the groundwater pressure is 1 nstrain. The altitude of the well is about 1040m and the depth of the screen is 640 m. It means that we can observe the volumetric strain at the depth of 640 m or at the altitude of 400 m by measuring the groundwater pressure.

After 1998 there were two eruptions at Mt.Ontake. One is the 2007 eruption, which occurred in March, 2007. The other is the 2014 eruption, which occurred in September 2014. A few months before the 2007 eruption, a relatively large crustal deformation, which was the gradual increase in the length of the baseline crossing Mt Ontake, was observed(Fig.2) although no such crustal deformation was observed in the 2014 eruption (Fig.3). At the 2007 eruption the groundwater pressure at GOT dropped 20 cm during almost the same period when the length of the baseline gradually increased(Fig.2) although no such groundwater pressure change was also observed(Fig.3). The 20cm drop in the groundwater pressure means 100 nstrain increase in the volumetric strain at GOT. The precursory gradual increase in the length of the baseline is converted into about 300 nstrain increase in the linear strain along the baseline. These two values are well-matched. In the presentation we will report the details of those groundwater pressure changes and the crustal deformation.

Fig.1 Distribution of the observation stations. A solid circle (GOT) is a groundwater observation station of GSJ,AIST. Four solid squares are GNSS stations of Geospatial Information Authority of Japan(GSI). A solid triangle is a tilt observation station of Japan Meteorological Agency (JMA).

Fig.2 Observation results during the period from Jan. 2006 to Dec.2007.

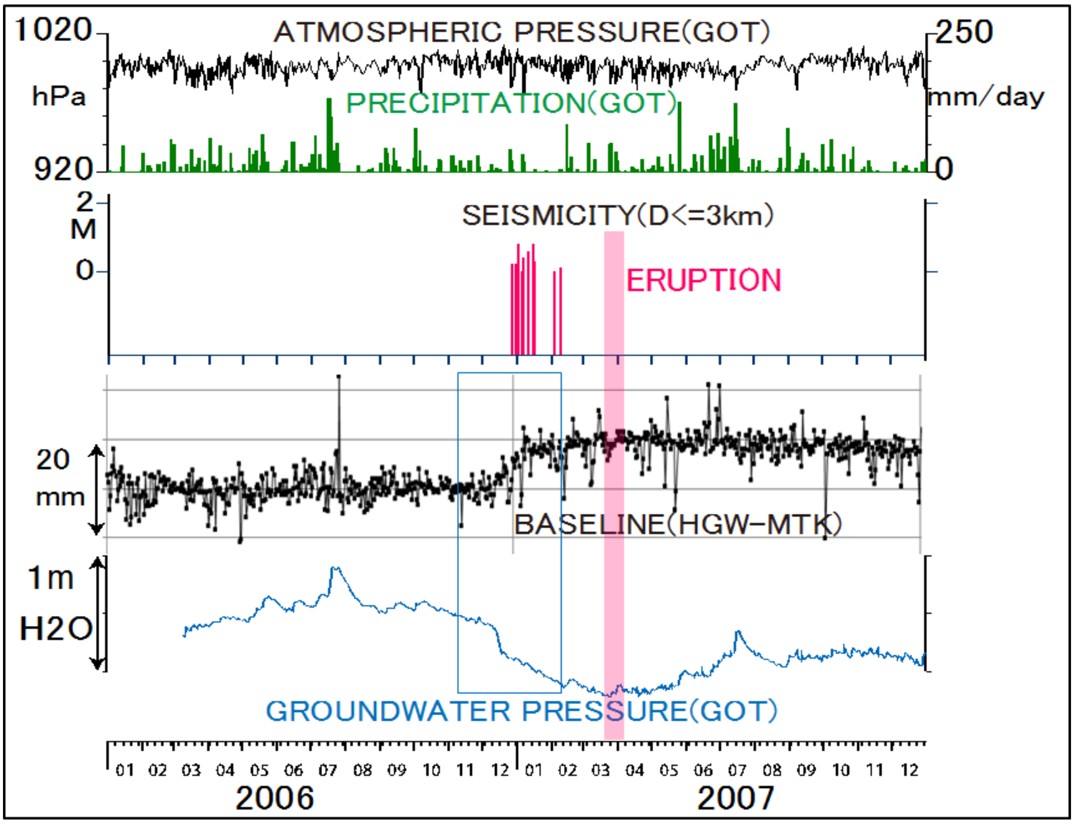
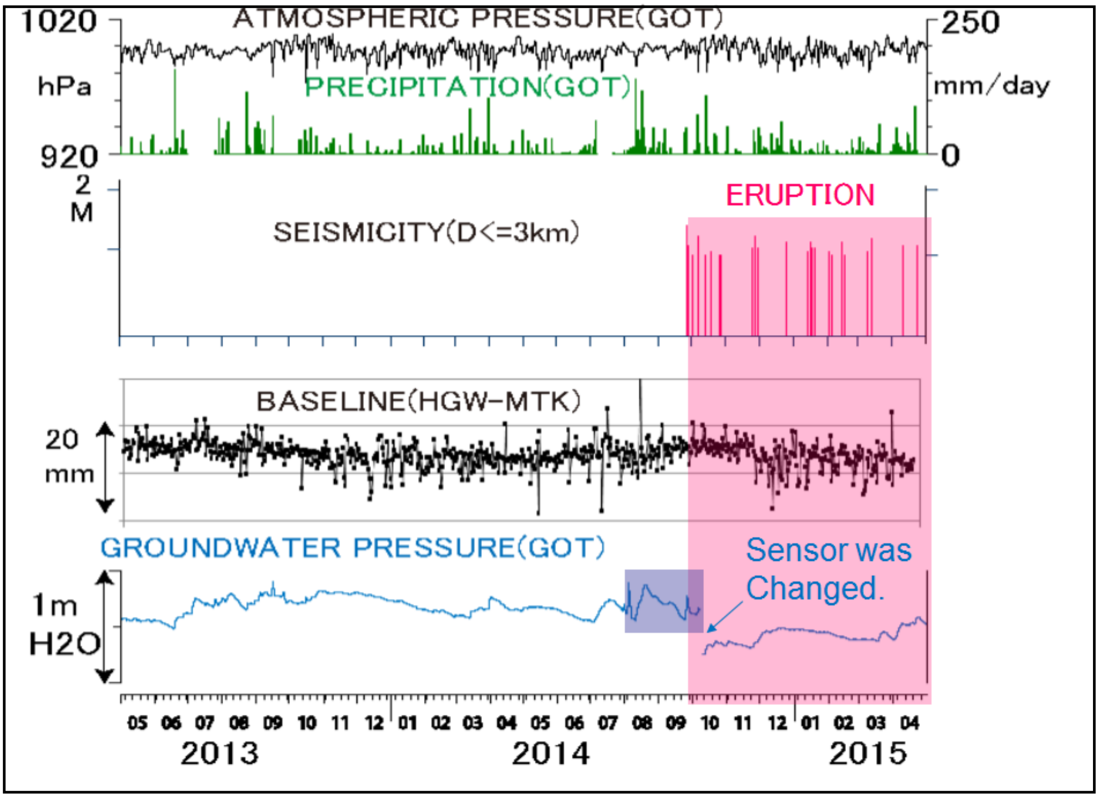


Fig.3 Observation results during the period from May 2013 to April 2015. The water pressure sensor had some trouble in August and September in 2014 and the groundwater pressure was superficially fluctuated. We changed the sensor in October 2014.



Investigation on fluid migration seismicity in association with fault zone damage: case study for 1999 M7.6 Chi-Chi, Taiwan, earthquake

Kuo-Fong Ma[1], and Hidemi Tanaka[2]

1. Department of Earth Sciences, National Central University, Taiwan
2. Graduate School of Science, University of Tokyo, Japan

Fluid had been considered as a possible factor in triggering earthquakes, but, the evidence in elucidating the behavior and mechanism is still unresolved. Our previous studies in attenuation, noted as 1/ Qs, for the 1999 Chi-Chi earthquake suggest that the fracture zone associated with fault zone could be considered as a fluid reservoir, which possibly yield to some observations/detections of phenomena associated with pre-, co- or post-seismic of a larger earthquake. The sudden changes in attenuation co-seismically with decay following a diffusion process indicated possible high pore-fluid saturation within fractured fault zone from fully to partial saturation. We suspect this process might yield the migration of fluid flow, and thus, related to the occurrence of some aftershocks. Aftershock sequence following a mainshock was often considered to be related to regional tectonic stress and stress triggering of a mainshock. For stress triggering, it refers to the seismicity in the stress increase regime with some lapse time (>one month) for the static stress triggering. In this study, we tried to deviate the possible fluid associated aftershocks by focusing on the stress decrease regime and 1-3-month aftershock sequence to understand their possible association. The migration of fluid flow increases the pore-pressure, which reduce the normal stress, and, thus, yield the co-seismic negative Coulomb's stress regime to become positive to trigger these fluid flow associated aftershocks. For the study of the Chi-Chi earthquake sequence, from the elapse time versus distance of the seismicity in this regime suggest a fluid flow of about 220m/day. We investigate the possible passage of fluid flow in the regime and understand its transient behavior associated with the fault zone damage and healing process.

Monitoring of seismic velocity using ACROSS around Nojima fault rupture zone and Tokai subduction zone in Japan

Ryoya Ikuta*[1], Toshiki Watanabe[2], Takahiro Kunitomo[3], Kin-ya Nishigami[4], Koshun Yamaoka[3]

1. Department of Science, Shizuoka University, Japan
2. Earthquake Research Institute, University of Tokyo, Japan
3. Research Center for Seismology and Volcanology, Nagoya University
4. Disaster Prevention Research Institute, Kyoto University

This manuscript reports the recent results of seismic velocity monitoring around an active fault and a subduction zone using artificial vibration sources named ACROSS. The ACROSS is a system designed to monitor the temporal variation in the seismic velocity, as its name stands for Accurately Controlled, Routinely Operated Signal System (Yamaoka et al.,2001). Now we have five ACROSS sources in Japan. One is monitoring a fault, another is monitoring a volcano, and others are monitoring a subduction zone.

The first ACROSS was built in 1998 on southern end of the Nojima fault, which ruptured during the 1995 Kobe earthquake (M7.2), to monitor recovery of the fault strength just after the large earthquake (Fig.1). In the initial few years of the monitoring, this Nojima ACROSS detected a strong preferred orientation of the crack to the along-fault direction. During the experiment, sudden delays in travel times for the S wave were observed associated with tele-seismic shakings. The S wave delay was polarized in the direction perpendicular to the fault, which means that the S wave splitting was enhanced by the strong shakings. The time decaying pattern of the delay suggests sudden increase and dispersion of the pore pressure.

We have conducted the monitoring using the Nojima ACROSS for 15 years to detect gradual increase of P and S wave velocity for about 0.1%. The increase corresponds to a decrease of permeability around the fault monitored by injection experiment. The seismic velocity change may be related to healing of the fault rupture zone.

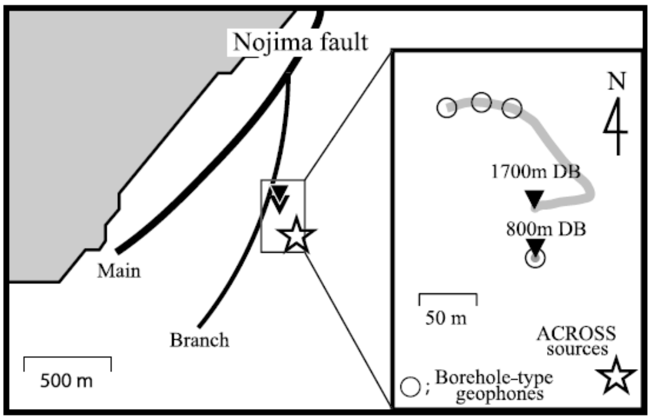


Figure 1. Location of the ACROSS vibrators (open star) and the seismometers. The solid triangles denote the 1700-m and the 800-m-deep boreholes. The enlarged map at the bottom right shows the configuration of the observation system. The thick gray lines are traces of the 1700-m and the 800-m-deep boreholes. The open circles denote borehole-type seismometers.

Other three ACROSS systems have been deployed in Tokai region, Japan, where the Philippine Sea plate subducts beneath Eurasian plate, to monitor the seismic velocity change associated with the plate convergence. We show the result using the source deployed in Mori (Fig.2). This Mori ACROSS started the monitoring in 2009. We analyzed the seismic velocity change using the data of 13 Hi-net stations (NIED) within 50 km from the ACROSS source. The S wave travel time showed gradual advance at the most stations, which was up to 0.01%/yr. Associated with the 2011 Tohoku Oki earthquake, the travel time of S waves at the most stations showed delay, which was up to 0.03%. We cannot find any significant relationships between the spatial pattern of the secular/co-seismic travel time changes and the crustal strain observed by GEONET (GSI). The secular and co-seismic travel time changes occurred in the opposite sense, which corresponds to the relationship between the secular and the co-seismic areal strains.

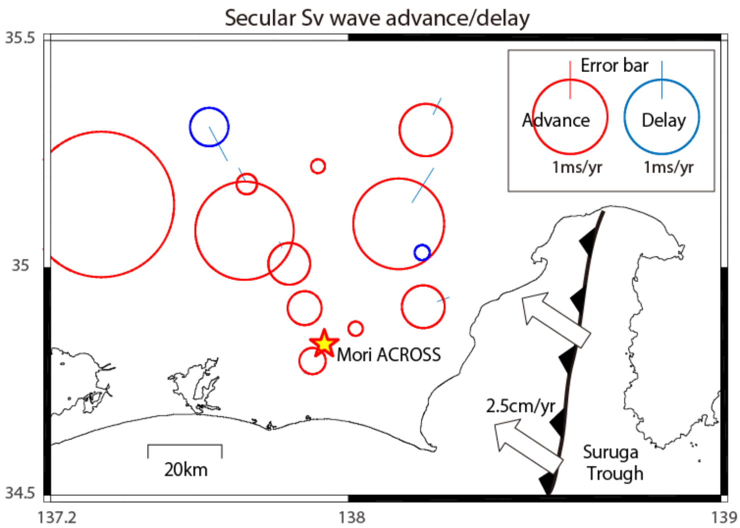


Fig.2 Location of Mori ACROSS and the secular variation of Sv wave travel time detected at the Hi-net stations.

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Regional variation of CH_4 and N_2 production processes in deep aquifers associated with the accretionary prism in Southwest Japan

Hiroyuki Kimura, Makoto Matsushita, Shugo Ishikawa
Department of Geosciences, Graduate School of Science, Shizuoka University, 836 Oya, Suruga-ku, Shizuoka 422-8529, Japan.

An accretionary prism is composed mainly of ancient marine sediment scraped from a subducting oceanic plate at a convergent plate boundary. Large amounts of anaerobic groundwater and natural gas, mainly methane (CH_4) and nitrogen (N_2), are present in the deep aquifers associated with an accretionary prism, but the origins of these gases are poorly understood.

Our present study revealed a regional variation in the CH_4 and N_2 production processes in the deep aquifers of the accretionary prism in Southwest Japan known as the Shimanto Belt. Stable carbon isotopic and microbiological analyses revealed that the CH_4 is produced through nonbiological thermal decomposition of organic matter in the deep aquifer of the coastal area near the convergent plate boundary, whereas a syntrophic consortium of hydrogen (H_2)-producing fermentative bacteria and H_2-using methanogens contributes to the significant CH_4 production observed in the deep aquifers of the middle and mountainous areas associated with the accretionary prism. Our results also suggest that N_2 production through the anaerobic oxidation of organic matter by denitrifying bacteria occurs particularly in the deep aquifer of the mountainous area in which the groundwater is affected by rainfall.

Overall, our results lead us to the conclusion that dynamic groundwater flow and the ongoing biodegradation of organic matter in the ancient sediments contribute to the CH_4 and N_2 reserves in the deep aquifers associated with the accretionary prism in Southwest Japan.

Earthquake Precursory Studies Using Continuous Soil Gas Monitoring Data in Taiwan: An Overview

Vivek Walia[1]*, Ching-Chou Fu[2,3], Tsanyao Frank Yang[2#], Arvind.Kumar[1],
Shih-Jung Lin[1], Cheng-Hong Chen[2] and Kuo-Liang Wen[1,4]

[1] National Center for Research on Earthquake Engineering, National Applied Research Laboratories, Taipei, Taiwan (vivekwalia@rediffmail.com, walia@ncree.narl.org.tw)
[2] Department of Geosciences, National Taiwan University, Taipei-106, Taiwan
[3] Institute of Earth Sciences, Academia Sinica, Taipei 115, Taiwan
[4] Department of Earth Sciences and Institute of Geophysics, National Central University, Jhongli, Taiwan

The island of Taiwan is a product of the collision between Philippine Sea plate and Eurasian plate which makes it a region of high seismicity. Active subduction zones occur south and east of Taiwan. After the destructive Chi-chi earthquake (M_W = 7.6, Sept. 21, 1999) an accelerated phase of geochemical monitoring started in Taiwan. Measurement of soil-gas emissions along active zones is characterized as a geochemical tool to identify and monitor tectonic activity in the region. Geochemical variations of soil-gas composition in the vicinity of the geologic fault zone of Northeastern and Southwestern parts of Taiwan have been studied in detail recently. To carry out the investigations, variations in soil-gases compositions were measured at continuous earthquake monitoring stations along different fault zones in regions under the study. Before selecting a monitoring site, the occurrence of deeper gas emanation was investigated by the soil-gas surveys which is followed by continuous monitoring of some selected sites with respect to tectonic activity to check the sensitivity of the sites. Based on the results of long term geochemical monitoring at the established monitoring stations we can divide the studied area in two different tectonic zones. We proposed tectonic based model for earthquake forecasting in Taiwan and tested it for some big earthquakes occurred during the observation period. Based on the anomalous signatures from particular monitoring stations we are in a state to identify the area for impending earthquakes of magnitude ≥ 5 and we have tested it for some earthquakes which rocked the country during that period. It can be concluded from the study that the stress/strain transmission for a particular earthquake is hindered by different tectonic settings of the region under study. The stress-induced variations due to impending earthquakes in soil-gas are contaminated by meteorological changes and, hence, assessment and quantification of these influences are a major prerequisite in the isolation of precursory signals. An effort has been made to reduce the noise level, which may be due to meteorological parameters by using different statistical filters. In an effort to reduce the response time and increase the efficiency, the automatic operating methodology was adopted to process the data from the monitoring stations. The data from the monitoring stations were automatically uploaded to the web service which provides the data management/exhibition with less response time database. In addition to monitoring station data, seismic parameters (i.e. Magnitude/location/depth of the event, the intensity/epicentral distance at a monitoring station, etc.) and meteorological parameter data are also uploaded from Central Weather Bureau of Taiwan (www.cwb.gov.tw) simultaneously. It would be helpful in increasing efficiency of earthquake prediction studies.

#This Abstract and Talk will be dedicated to Late Profosser Tsanyao Frank Yang (1961-2015)

Radon concentration distributions of deep groundwater around Tachikawa fault

Fumiaki Tsunomori [1,*] and Tomoya Shimodate [2]

[1] The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[2] International Christian University, 3-10-2 Osawa, Mitaka, Tokyo 181-8585, Japan

Distribution of groundwater radon concentration around the Tachikawa fault was surveyed. A mean radon concentration of the shallow groundwater was similar to the value that was reported by Saito in 1993. A contrast of the radon distribution on both sides of the Tachikawa fault slightly changed in comparison to that reported by Saito. According to the Tokyo Statistical Yearbook, the Musashino plateau in the northeast of the Tachikawa fault was developed for residential zone from farmland. This urbanization might suppress the recharge of meteoric water into shallow aquifers. A mean radon concentration of the deep groundwater was comparable with the value of the shallow groundwater. This supports that the geology around the Tachikawa fault consists of sediment rocks that was supplied from the mountain area of Tokyo without hypogene rocks. However, except a few sampling points, the radon concentrations of deep groundwater along the Tachikawa fault were significantly higher than that of groundwater from an aquifer contained in a bedrock. It is presumed that this distribution arises from the development of a fault fracture zone around the Tachikawa fault.

Anomalous decrease in groundwater radon and dissolved-gases before the Taiwan and Japan earthquakes

T. Kuo [1] and F. Tsunomori [2]

[1]Department of Mineral and Petroleum Engineering, National Cheng Kung University, Tainan, Taiwan

[2]Laboratory of Earthquake Chemistry, Faculty of Science, The University of Tokyo, Tokyo, Japan

Recurrent groundwater radon anomalous declines were observed at well D1 in the Antung hot spring in eastern Taiwan prior to the four major earthquakes – (1) 2003 Mw 6.8 Chengkung, (2) 2006 Mw 6.1 Taitung, (3) 2008 Mw 5.4 Antung, and (4) 2011 Mw 5.0 Chimei. The epicenters are located 24 km, 52 km, 13 km, and 32 km, respectively, from well D1. Similarly, an anomalous decrease in radon concentration was observed in groundwater at well SKE-1 near Nakaizu in Japan prior to the 1978 Izu-Oshima-Kinkai earthquake of magnitude M 7.0. The epicenter is located 25 km from well SKE-1. Radon volatilization into the gas phase can explain the anomalous decrease of radon precursory to the above earthquakes.

Simultaneous concentration declines in groundwater-dissolved radon and methane were observed prior to the 2008 Mw 5.4 Antung earthquake. Concurrent concentration declines in groundwater radon, methane, and ethane were also observed prior to the 2011 Mw 5.0 Chimei earthquake. Similarly, an anomalous decrease in methane concentration was observed at Byakko spring prior to the 1984 western Nagano Prefecture earthquake of magnitude M 6.8. The epicenter is located 50 km from Byakko spring. The above observations in Taiwan and Japan also suggest that radon due to its stable background is the best-choice tracer among the groundwater-dissolved gases for strain changes in the crust preceding an earthquake.

Change of Rock Permeability Induced by the 2011 Tohoku Earthquake

Chihiro Kinoshita*[1] ,Yasuyuki Kano[1], Naoji Koizumi[2] and Hisao Ito

1. Research Center for Earthquake Prediction, Disaster Prevention Research Institute, Kyoto University, Japan
2. AIST, Geological Survey of Japan, Active Fault and Earthquake Research Center

We have been monitoring the pressure of groundwater at the Kamioka mine in Gifu prefecture, central Japan. Kinoshita et al. (2015) observed a large pressure decrease which is equivalent to over 2 m change in water level after the 2011 Tohoku earthquake(M9.0), although the hypocentral distance is more than 500 km.

Kinoshita et al. (2015) hypothesized that new water paths were made associated with the shaking from the earthquake and the rock mass became more permeable, because the pressure decreases continued for several days. To verify the hypothesis, we calculated the hydraulic diffusivity from the response of the pressure to Earth tides. Earth tides induce expansion and contraction of the crust, and pore pressure responses to this deformation. The pressure change from theoretical strain changes of the Earth tides can be calculated and subtracted from the observed pore pressure data. Then, we can extract the hydrological rocks property from the residual pore pressure.

We used the tidal analysis program BAYTAP-G (Tamura et al., 1991) to calculate the Earth tide response and focused on the M_2 and O_1 constituents which are the largest. The M_2 and O_1 amplitudes decreased after the Tohoku earthquake. We estimated the hydraulic diffusivity from those results and showed there was remarkable increase after the earthquake. To try to understand the cause of the permeability change, we compared the effects of both static and dynamic strain associated with the earthquake, but there is no clear difference. Kinoshita et al. (2015) could not conclude from those results whether static or dynamic strain has a dominant effect.

The Geological Survey of Japan, AIST has developed a network of groundwater monitoring in Japan since 1976 (Itaba et al., 2008). We investigated the groundwater levels and pressure changes before and after the Tohoku earthquake using the AIST boreholes. Among the factors influencing groundwater changes, at first, we focus on the effect of differences in boreholes lengths. Each observation site of AIST used for the present analysis has two or three boreholes with different lengths. We investigated the groundwater responses of each borehole and depth in terms of confined and unconfined aquifers.

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Temporal changes of earthquake-related groundwater-level

Ching-Yi Liu[1], Yeeping Chia[1], Yen-Chun Kuan[2], Kai-Wen Kuo[3]
[1] Department of Geosciences, National Taiwan University, Taipei, Taiwan, R.O.C.
[2] Water Resources Agency, Ministry of Economic Affairs, R.O.C.
[3] Central Weather Bureau, Ministry of Transportation and Communications, R.O.C.

Taiwan is located at the boundary between the Eurasian plate and the Philippine Sea plate, which is in the tectonic active region where earthquakes occur frequently. Changes in groundwater-level induced by earthquakes have been recorded in many monitoring wells installed in the plain area of the island. From groundwater level record, there are two types of co-seismic groundwater level changes, one is oscillatory change and the other one is sustained change. Sustained groundwater-level changes during earthquakes are often observed in the confined aquifer, whereas accompany oscillatory changes could only be recorded by high-frequency data logger. In this study, we analyzed long-term monitoring data at two single wells, one is Pingding (PD) and the other is Liujar (LJ). PD well is located at the top of the northern tip of Douliu Hills, groundwater-level is monitored in 1-hour interval, and temporal changes recorded mostly co-seismic rises. LJ well is located west of the foot of the Western Foothills, recorded with 1-Hz monitoring data, and temporal co-seismic changes are falls. From the results of the two wells, it is speculated that co-seismic change reflect the hydrogeological condition of aquifer or the redistribution of crustal strain, and indicate the local stress field changes over time.

Keywords: temporal change, groundwater level, co-seismic

Ascension of Fluid from Mud Volcanoes Distributed along Anticline and Fault Zones

Keiji Asano[1], Kazuhiro Tanaka[1], Koichi Suzuki[2],
Lai Wen-Chi[3] , Nariaki Nishiyama[1]

[1]Graduate School of Science and Engineering, Yamaguchi University, Yamaguchi, Japan

[2]Geosphere Science Sector, Civil Engineering Research Laboratory, Central Research Institute of Electric Power Industry, Abiko, Chiba, Japan

[3]Disaster Prevention Research Center, National Cheng Kung University, Taiwan City, Taiwan

Mud volcanoes, which are often distributed in oil and gas fields, are conical mounds that consist of mud and breccia. The material ejected from mud volcanoes ascends from deep underground and is expelled by abnormal water pressure. Mud volcanoes have heights ranging from a few meters to tens of meter up to 500 m. Because natural disasters caused by mud volcanism are a concern, the spatiotemporal activity of mud volcano should be evaluated when selecting the site of underground facilities such as geological disposal facilities for high-level radioactive waste. Active inland mud volcanoes are distributed in southwest Taiwan and are situated along the axes of anticlines and faults (Hamada *et al*., 2009). The controlled source audio-frequency magnetotelluric method (CSAMT) has been used to determine the distribution of low-resistivity zones in Niigata Prefecture, Japan, and showed that mud volcanoes along an anticline axis have underground mud chambers.

Here, we conducted geological surveys and geochemical analyses of groundwater and gas expelled from mud volcanoes distributed along the Chishan fault and along the Gudingkeng anticline axis in southwest Taiwan. Also, we performed geophysical exploration by the CSAMT method around the Wushanding mud volcanoes distributed along the Chishan fault to identify underground structures and the paths of fluid ascending from deep underground. As a result, we found that the expelled fluid ascends from a shallower depth for mud volcanoes distributed along the anticline axis than for those distributed along the fault. In the case of the anticline axis, the fluid is stored near the ground surface in mud chambers under the mud volcanoes. Gas pressure increases by degassing in the shallow underground mud chambers and many cracks are generated in the impermeable cap rock. The cap rock then breaks and fluid erupts to the ground surface for some period, forming the caldera structure. On the other hand, the fluid expelled from mud volcanoes distributed along the fault ascends through the fault, and some of the fluid is expelled directly from the fault and some migrates to the anticline axis, where it is trapped temporarily under the cap rock before ascending to the surface without intense activity.

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

Wen-Chi Lai[1], Shih-Jung Wang[2], Kuo-Chon Hsu[3] and Chjeng-Lun Shieh[1]

1. Disaster Prevention Research Center, National Cheng Kung University, Taiwan
2. Georesources Research Center, National Cheng Kung University, Tainan, Taiwan
3. Department of Resources Engineering, National Cheng Kung University, Taiwan

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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