Late Holocene uplift of the Izu Islands on the northern Zenisu Ridge off Central Japan: Implication for the tsunami source area of the AD 1498 Meio earthquake

*Akihisa Kitamura[1], Yuta Mitsui[1], Yosuke Miyairi[2], Yusuke Yokoyama[2], yuki Tokuda[3]

1. Institute of Geosciences, Faculty of Science, Shizuoka University, 2. Atmosphere and Ocean Research Institute, University of Tokyo, 3. Tottori University of Environmental Studies

The 25 August 1498 Meio earthquake (*M* 8.2–8.4) is thought to have been caused by rupture along the Nankai Trough, off southwest Japan. However, another possible interpretation is that the rupture area extended north to the Zenisu Ridge, off southeast coast of Izu Peninsula. Examination of the co-seismic uplift caused by the Meio earthquake along the northern Zenisu Ridge allows us to assess the rupture area of this event. We analyze the elevation and ^{14}C dates of emerged marine sessile assemblages on the islands of Niijima, Jinaijima, Shikinejima and Kozushima on the northern Zenisu Ridge. The results show that uplift events took place after 1950 AD (uplift event 1) and at some time during 1810–1950 AD (uplift event 2), 786–1891 AD (uplift event 3), 600–1165 AD (uplift event 4), and 161–686 AD (uplift event 5), although uplift events 4 and 5 are identified only at Kozushima. Based on the present-day elevational distributions of species, the uplift amounts were estimated to be 0.2–0.9 m (uplift event 1), 0.2–0.4 m (uplift event 2), 0.3–2.6 m (uplift event 3), 1.6–4.4 m (uplift event 4) and 8.2 m (uplift event 5). Uplift event 1 was caused by dike intrusion related to the 2000 AD eruption of Miyakejima Volcano near Kozushima. Uplift event 2 was probably caused by strong earthquakes (i.e. M_w ~6) and/or dike intrusion. Possible mechanisms for uplift event 3 include strong earthquakes, dike intrusion and the AD 1498 Meio earthquake. It is likely that uplift events 4 and 5 were caused by lava-dome formation during the AD 838 eruption and previous volcanic activity in Kozushima, respectively. These findings do not preclude the possibility that the AD 1498 Meio earthquake caused uplift event 3 at Shikinejima and Kozushima. However, based on our data and those of other recent studies, we propose that the 1498 AD Meio earthquake occurred along the Nankai Trough and that rupture of the fault around the southern margin of the northern Zenisu Ridge caused both co-seismic uplift of the study area and the historically recorded AD 1495 earthquake and tsunami at Sagami Bay.

Keywords: AD1498 Meiou earthquake, Izu islands, emerged marine sessile assemblages, 14C dating

Location and depth of the 1855 Ansei Edo earthquake inferred from seismic intensity characteristic

*Ryoichi Nakamura[1], Kenji Satake[1], Takeo Ishibe[2], Jun Muragishi[1], Akihito Nishiyama[1]

1. Earthquake Research Institute, The University of Tokyo, 2. Association for the Development of Earthquake Prediction

The 1855 Ansei Edo earthquake (hereafter, the 1855 earthquake) occurred on 2nd day of 10th month in 2nd year of Ansei era (November 11th, 1855 on the Gregorian calendar) and caused severe damage in and around Edo City, former Tokyo Metropolis. While detail seismic intensity distribution from this earthquake has been studied (Usami, 1994, private publication; Nakamura and Matsu' ura, 2011, Historical Earthquakes), the earthquake epicenter and depth has been controversial; whether it was a shallow crustal earthquake or a deep one (down to 100 km depth). One of the reasons for this ambiguity is a non-circular shape of isoseismals resulting from a heterogeneous attenuation (Qs) structure (Nakanishi and Horie, 1980, JPE; Nakamura et al., 2007, Historical Earthquakes) due to a complex plate configuration; the Philippine Sea Plate (PHS) and Pacific Plate (PAC) subduct from the south and east, respectively, beneath Tokyo. However, from recent studies, it is unlikely that the 1855 earthquake was a shallow crustal earthquake, according to S-P times estimated from historical literature (Nakamura et al., 2003) and our previous study (Nakamura et al., 2014, 2015) which showed that the felt area can be explained by intermediate-depth earthquakes.
In this study, we re-examined the characteristics of the seismic intensity distribution for the 1855 earthquake by comparing with the seismic intensity distribution of recent earthquakes observed by the Japan Meteorological Agency (JMA), as well as with those calculated using a 3-D attenuation Qs model. We concluded that the 1855 earthquake was either an intra-plate earthquake within PHS at depth of around 50 km or an inter-plate earthquake between PHS and continental plate (depth around 30 km). The seismic intensity distributions for both the 1855 earthquake and recent inter-plate earthquakes between PHS/PAC (depth 60-80 km) show common characteristics that seismic intensities in the western Tokyo are smaller than those in eastern and southern Tokyo, which we call "the property of constriction" (Nakamura et al., 2007, Historical Earthquakes). However, the seismic intensity along the cross section are quite different (Figure 1(a)); the 1855 intensity has a peak near central Tokyo, while those from an inter-plate (PHS/PAC) earthquake are smaller at central Tokyo than at central Kanagawa Prefecture (southwest of Tokyo Metropolis). This result implies that the 1855 earthquake was not an inter-plate earthquake between PHS/PAC.
We then calculated seismic intensity distribution by using a 3-D attenuation Qs structure (a block size of 0.1 deg*0.1 deg*5 km) estimated by using the K-NET and KiK-net records during 1996-2016.7. Figure 3 is a example of seismic intensity distribution calculated for an intra-plate earthquake assuming at a depth of 50 km. The seismic intensity distributions of earthquakes within the PHS slab at depths of 40-60 km have the property of "constriction". Even if the epicenter is shallower than 60-80 km, the property of "constriction" is created, and the seismic intensities near central Tokyo become larger as the hypocentral depth becomes shallower. These support that the earthquake source was within or on the upper boundary of PHS slab.

Acknowledgment: This study was supported by the "Special Project for Reducing Vulnerability for Urban Mega Earthquake Disasters" under the Ministry of Education, Culture, Sports, Science and Technology of Japan.

Keywords: 1855 Ansei Edo earthquake, Abnormal seismic intensity distribution, Hypocentral depth, Attenuation structure

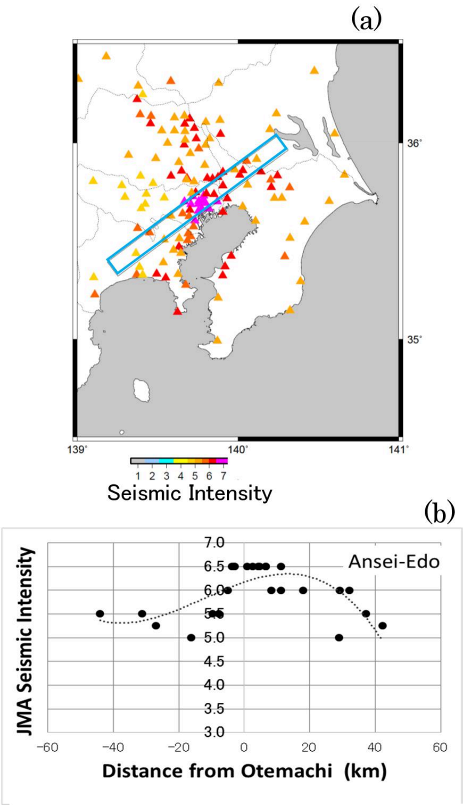


Fig.1 Ansei Edo earthquake
Usami(1994) The Japan Electric Association

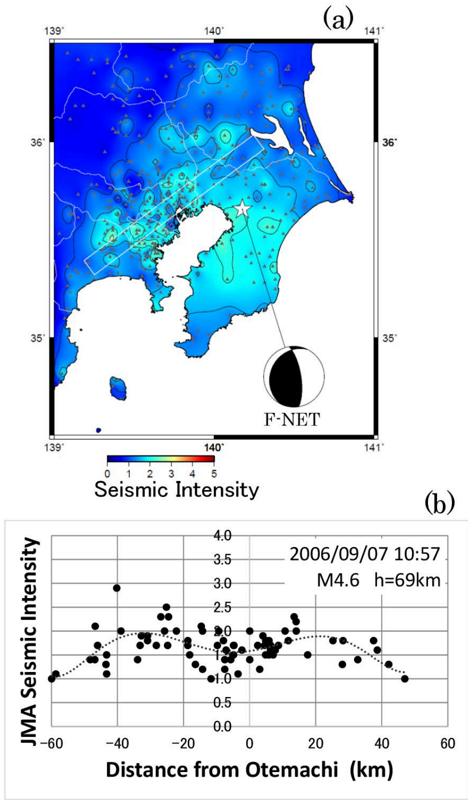


Fig2 PHS/PAC plate boundary
JMA data

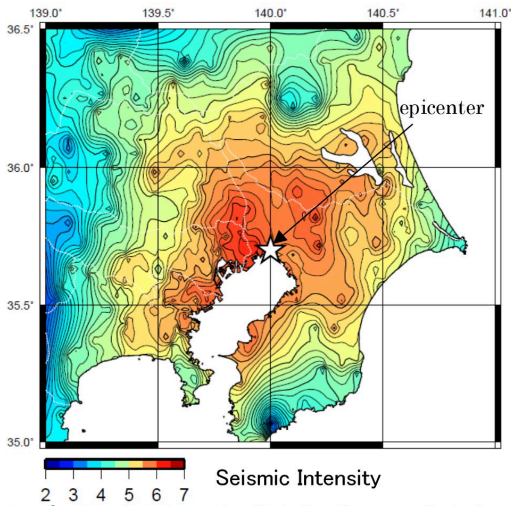


Fig.3 An example of seismic intensity distribution predicted assuming 50 km depth

Earthquake characteristics of 1885 Ansei Edo earthquake presumed by earthquake anomalies and housing damages - preliminary report on NNE-SSW trending an earthquake fault

*Isamu Toyokura[1]

1. Geo-Toyokura Professional Engineer's Office

Ansei Edo earthquake hit the central part of Edo city, 1855 in Edo period and brought large damages to both Edo governmental system and people living there. Various records of earthquake anomalies and housing damages are preserved. Therefore, I have been making an attempt to analyze the characteristics of the earthquake and earthquake fault based on these historical data.
I will discuss the possibility of NNE-SSW trending earthquake fault in the eastern part of the Yamanote upland.

Keywords: Ansei Edo earthquake, earthquake lighting, NNE-SSW trending earthquake fault, concealed fault in the metropolitan area, damage distribution

Can felt reports of historical documents be used to estimate the source of large earthquakes? - Evaluation of applicability to historical large earthquakes -

*Takeo Ishibe[1], Ritsuko S. Matsu'ura[1], Koji Iwasa[1], Ryoichi Nakamura[2,3], Kenji Satake[3]

1. Association for the Development of Earthquake Prediction, 2. Tokyo Electric Power Services Co., Ltd., 3. Earthquake Research Institute, the University of Tokyo

Can felt reports of historical documents be used to estimate the source of large earthquakes? Before establishing a new methodology, we show that the source area of recent three large earthquakes (2004 Niigata-Ken Chuetsu, 2008 Iwate-Miyagi, and 2011 Fukushima-Hamadori earthquakes) can be imaged from the spatial distribution of felt reports by using the JMA seismic intensity database. Our preliminary results imply the possibility that the large earthquake source can be constrained from spatial and temporal distribution of felt reports.
For the case of the 2004 and 2008 earthquakes, number of aftershocks with felt reports decreases with increasing distances at epicentral distances <100 km from the mainshock, while they fluctuate at epicentral distances >100 km, probably due to site condition and/or attenuation structure. This indicates that the effects of site amplification near surface and heterogeneous attenuation structure should be properly taken into consideration to estimate source of historical earthquakes. For the case of the 2011 earthquake, the number of aftershocks with felt reports fluctuated even at epicentral distances <100 km from the mainshock, because of the aftershocks following the 2011 Tohoku-oki earthquake. The areas imaged from the number of felt reports were well concordant with aftershock area following these mainshocks even after thinning out the observation stations as long as the station coverage was retained.
In Japan, abundant historical literature during over 1,000 years is preserved; these have been used for estimating a source of a historical large earthquake (e.g., Usami *et al.*, 2013) and for revealing recurrences of great interplate earthquakes along the Nankai Trough (e.g., Ishibashi and Satake, 1998). Sources of historical large earthquakes have been traditionally estimated from seismic intensity distribution on the basis of damage for building structures and casualties recorded in historical literature. However, the damage was not necessarily caused by a ground shaking but also tsunami, massive fire and/or landslide. In addition, the distribution of building damage is strongly controlled by the population density and elapsed years since constructed. Thus, the estimated source of a historical large earthquake is possibly biased to a densely populated area.
In some historical literature, felt reports without any damage are also documented as well as damage description from major earthquakes. Most of historical documents only described ‘earthquake with felt’ as well as the date and time, whereas some of them particularly recorded the number of earthquakes with felt in each day with the intensity of ground shaking. On the basis of felt reports, it has been revealed that the seismicity rate increased in the central and northern parts of the Kinki district before and after the great Nankai earthquakes (Oike, 1996) and that the seismic quiescence possibly happened preceding to the 1861 Miyagi-oki earthquake (Matsu’ura and Tsuji, 2010). However, felt reports were not fully utilized except for several previous studies (e.g., Matsui and Oike, 1997; Satake, 2002).

Keywords: Felt reports, JMA seismic intensity database, 2004 Niigata-Ken Chuetsu earthquake, 2008 Iwate-Miyagi earthquake, 2011 Fukushima-Hamadori earthquake

Examples and types of misdates in catalogs of Japanese historical earthquakes and associated materials

*Yasuyuki Kano[1]

1. Research Institute for Earthquake Prediction, Disaster Prevention Research Institute, Kyoto University

Dating of earthquakes is a basic practice in studies of historical earthquake. Incorrect dates of earthquakes sometimes occur because of (1) mistakes in the original material, (2) mistakes in compilation of material, such as historical records of local governments, and (3) mistakes in editing collections of materials for historical earthquakes. Eight examples are presented that show the corrected dates and causes of the error. These results may help to find other misdates in historical earthquakes, which will lead to better understanding of past earthquake occurrence.

Keywords: Fake earthquake, Misdate, 1707 Hoei earthquake, 1831 Aizu earthquake, 1847 Zenkoji earthquake, 1858 Hietsu earthquake

Is mortality an indicator for the location of epicenter of inland great historical earthquakes? –a case study of the Hyogo-ken Nanbu Earthquake in 1995-

*Taku Komatsubara[1]

1. Institute of Geology and Geoinformation, Advanced Industrial Science and Technology

1 Introduction Some historical earthquake researchers propose that mortality is a source for estimation the locality of inland earthquake epicenter (e.g. Tsuji, 2010). This methodology based on the following two assumpyions. 1. Human beings attempt to escape from collapsing residential houses immediately after perception the preliminary trmors. 2. Thus, there should be a close relationship between duration of preliminary tremors (i.e. epicentral distance) and survival rate. Former sudies (e.g. Komatsubara, 2016) applied this persupposition to rural nighttime earthquakes which are acceptable such assumptions, and concluded the mortality is better indicator than the fallen house ratio. In the dense populated cities , however, abiove mentioned assumptions are nonsensical, because even if persons coulld escape from residential houses, vacant area would be blocked by fallen buildings, survival rate would consequently be reduced than rural areas. Therefore, it is worthy to test whether relationship between the duration of preliminary tremors and survival rate does occure or not. The presenter examines a case of the Hyogo-ken nanbu Earthquake in 1995, as a rudimentary test for applicability on this method to urban earthquake such as the Ansei Edo Earthquake in 1855.
2 Outlinese of the 1995 Hyogo-ken Nanbu Earthquake The hyogo-ken Nanbu Earthquake (Mj=7.3) occurred at AM 5:46, its' epicenter was at the Akashi strait. The hypocenterical processes ware well analyzed by Sekiguchi et al, (2000). They made clear the processes as follows. 1. The first rupture initiated under the Akashi strait, west of Kobe City, and rupture expanded forward both sides. 2. The next break occurred just under Kobe City at five seconds after the initiation of the first rupture. 3. The third rupture occurred at the east end of the second rupture at nine seconds after the initiation of the first rupture. The presenter estimates mortality based on the address of victims (Mainichi Newspapers Co. Ltd., 1995). and basic redidents' registers of local goverments. The distribution of mortality is closely similar to the fallen buildings rate (Building Research Institute, 1996), and has less relationship with distance from epicenter.
3 Discussion and next theses This result shows there is a little relationship between mortality and epicentral distance in overpopulated areas. The presenter think of following three factors would be important on the severe mortality in distant place from epicenter. 1. Many two-storied low registant buildings collapsed, and many residents could not run off fallen houses although they tried. 2. Many persons died by collapsing buildings which blocked vacant ground. 3. Almost all people have studied "Crawl under desk or bed while shaking". This education is not effective at the case of hause falling. The second factor is common situation with the early modern cities. Thus, it must be cautious to make use of the survival rate to be an indicator of epicentral distance for historical earthquakes in urban areas. The presenter wants to continue studying on the mortality in rural Awaji Island by this earthquake. And statistical studies on relationships among mortality, rate of fallen buildings and epicentral distance in urban earthquake disaster are needed.

References

Mainichi Newspaper Co. Lyd. (1995)Documents Hanshin great earthquake disaster. 242p.
Building Research Institute (19969 Final report on the damages by the Hyogo-ken Nanbu Earthquake in 1995. 303p.
Komatsubara, T. (2016) Estimation on the location of epicenter of an inland earthquake inferred by the

distribution of the ratio of killen and/or injured persons to total population - A case study of the Ansei Hietsu Earthquake of April 9 in 1858, Gifu and Toyama prefectures, central Japan-. *Historical Earthquakes*, **31**, 1-7.
Sekiguchi, H., Irikura, K. and Iwata, T. (2000) Fault geometry at the rupture termination of the 1995 Hyogo-ken Nanbu Earthquake. *BSSA*, **90**, 117-133.
Tsuji, Y. (2010) Distribution of numbers of causalities in villages of the Echigo Sanjo Earthquake of December 20,
1828. *Chishitsu News*, 676, 16-20.

Keywords: historical earthquake, mortality, epicenter, Hyogo-ken Nanbu Earthquake, urban earthquake disaster

Active tectonics of the Futagawa fault zone over the last 300 ka

*Kiyokazu Oohashi[1], Tomonori Tamura[1], Marika Tozawa[2]

1. Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2. Faculty of Science, Yamaguchi University

The Futagawa fault zone which ruptured during the 2016 Kumamoto earthquake has several characteristic features in its seismicity, fault geometry and kinematics. We propose these features arise from transient properties due to the recent chage of tectonics in this region. During a geological survey after the 2016 Kumamoto earthquake, we found four fault outcrops along the Futagawa fault zone, which considered to ruptured with the earthquake (Kamijin, Sugidou, Kawahara, and Kuwazuru outcrop). The Kamijin outcrop is located between the places where surface ruptures of 2 m (dextral movement) are found. The sharp fault plane, which trends N66˚E and dips 90˚, juxtaposes cohesive(lower unit) and incohesive(upper unit) Aso-4 pyroclastic flow deposites. The fault displaces modern ground surface and shows dextral displacement of 2 m in maximum due to the 2016 Kumamoto earthquake. Based on the spatial distribution of the Aso-4 pyroclastic flow deposites, we estimate that the accumulated displacement of 10 m after the formation of the Aso-4 pyroclastic flow deposites. In convined with the results from other three outcrops, the recent average vertical slip rate of the Futagawa fault (< 90,000 yBP) ranges from 0.1~0.07 m/ky, which is much smaller than that obtained from the offset of the geological markers older than 90,000 yBP (1 m/ky, Watanabe et al., 1979, The Quaternary Research). In observations of minor faults in basement rocks, striations on fault gouges show almost horizontal dirction while that in cataclasites show almost vertical dirction. Hence we conclude that the vertical slip rate of the Futagawa fault zone becomes slower due to the recent change of slip direction from normal sence to dextral sence.

Keywords: The 2016 Kumamoto earthquakes, average slip rate, Striation, Fault rocks, Aso pyroclastic deposits

Recurrence interval of morphogenic earthquakes on the Futagawa-Hinagu Fault Zone that triggered the 2016 M_w 7.1 Kumamoto earthquake, SW Japan

*Aiming Lin[1], Takako Satsukawa[1], Kouichiro Sado[2], Nobukazu Takahashi[2], Soichiro Hirata[2]

1. Department of Geophysics, Graduate School of Science, Kyoto University, 2. Chiken Sogo Consultants Co. Ltd.

Large earthquakes of magnitude >6–7 with shallow focal depths can produce distinctive coseismic surface ruptures and cause strong ground deformation. Such large-magnitude earthquakes are called morphogenic earthquakes because they are capable of generating or modifying surface morphology instantaneously and permanently. Morphogenic earthquakes can generally be identified via trench surveys that reveal features of ground deformation preserved in sedimentary horizons.
The 2016 M_w 7.1 (Mj7.3) Kumamoto earthquake, which occurred in central Kyushu Island, southwest Japan, produced a ~40-km-long surface rupture along the Futagawa-Hinagu-Fault Zone (FHFZ) that cuts across Aso caldera. Field investigations related to the Kumamoto earthquake, trench excavations across the Hinagu and Futagawa faults, and radiocarbon dating results reveal that 1) prior to the 2016 earthquake, at least two morphogenic earthquakes occurred in the past ca. 2000 years on the Hinagu Fault, and four events in the past 4000–5000 years on the Futagawa Fault, suggesting an average late Holocene recurrence interval of 1000 years for morphogenic earthquakes within the FHFZ; and 2) the most recent event occurred between AD 1000 and 1400. These results contradict previous studies that estimate recurrence intervals for morphologic earthquakes of 3600-11,000 years and 8000-26,000 years on the target segments of the Hinagu and Futagawa faults, respectively. Our findings show that recent activity, including the recurrence intervals of large earthquakes and slip rates in the HFFZ, were previously underestimated; therefore, it is necessary to reassess the seismic hazard posed by the HFFZ, particularly for densely populated areas of Kyushu, Japan.

Reference: Lin et al. (2016). Coseismic rupturing stopped by Asovolcano during the 2016 Mw 7.1 Kumamoto earthquake, Japan. Science, 354, 869-875.

Keywords: 2016 Mw 7.1 Kumamoto earthquake, Futagawa-Hinagu Fault Zone, Recurrence interval of morphogenic earthquakes

Paleoseismic events along the Takano-Shirahata segment of the Hinagu fault zone revealed by trench investigation

*Yoshiki Shirahama[1], Yukari Miyashita[1], Takashi Azuma[1], Tetsuhiro Togo[1], Masao Kametaka[2], Yuji Suzuki[2]

1. Advanced Industrial Science and Technology, Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology, Active Fault Research Group, 2. Dia Consultants Co., Ltd.

Hinagu fault zone is extending from Kiyama in Kamimashiki District, Kumamoto Prefecture to the southern part of the Yatsushiro Sea. This fault zone is divided in three segments, Takano-Shirahata segment, Hinagu segment, and Yatsushiro Sea segment (Earthquake Research Promotion Headquarters, 2013). Associated with the 2016 Kumamoto earthquake sequence, approximately 6-km-long surface ruptures were produced by dextral strike-slip motion along the Takano-Shirahata segment (Shirahama et al., 2016). Even though we need to accurately estimate probability of large-scale earthquake occurrence, the paleoseismic history of the Hinagu fault zone is not well known. GSJ, therefore, conducted a trench investigation at the Hinagu fault zone to obtain more detail paleoseismic history such as the latest event or recurrence interval at two sites: Yamaide at the Takano-Shirahata segment and Minamibeta at the Hinagu segment. In this presentation, we will mainly introduce the paleoseismic history revealed by the trench investigation at Yamaide.

Soon after the 2016 Kumamoto Earthquake, our field investigation at Yamaide found small surface deformation resulting from a right-lateral strike-slip motion on the rice field where the east side was slightly upthrown. The trench, which is 14 m long, 10 m wide, and 4 m deep, was excavated across the southernmost part of the surface ruptures. Some reverse faults and deformed layers were obvious on the trench's wall surfaces. On the northern wall facing the south, two strands of reverse faults and on the southern wall four strands appeared. They steeply dipped to the east. Some layers composed of clastic sediments were possibly deposited by fluvial processes dipping towards the west and cut by those faults. The vertical displacements along some faults of older (lower) layers had accumulated more than younger (upper) layers. Some ^{14}C dating results showed the oldest humic silt layer in the trench deposited about 15 ka. This suggests that those faults were in active during the period of deposition after 15 ka. In this presentation, we will report the seismic history of the Takano-Shirahata segment of the Hinagu fault zone revealed by the trench investigation, and discuss the relationship with paleoseismic histories of other segments.

Keywords: Hinagu fault zone, 2016 Kumamoto Earthquake, Trench survey

Paleoseismic event of the Hinagu segment of the Hinagu fault zone investigated by a trench survey

*Tetsuhiro Togo[1], Yukari Miyashita[1], Takashi Azuma[1], Masao Kametaka[2], Toru Sakai[2], Kazuki Matsuura[2]

1. National Institute of Advanced Industrial Science and Technology, 2. Dia Consultants CO., Ltd.

Hinagu Fault zone is extending from Kiyama in Kamimashiki District, Kumamoto Prefecture to the southern part of the Yatsushiro Sea. The direction of this fault zone is generally in the northeast - southwest and which forms a distinct topographic boundary between the eastern margin of the Yatsushiro plain and the Kyushu mountainous region. The fault movement is regarded as a right lateral strike fault with relatively uplifting of the southeast mountainous side of the fault. From the activity history, this fault zone is divided in three segments, from north to south, Takano-Shirahata segment of 16km in length, Hinagu segment about 40km, and Yatsushiro Sea segment (Earthquake Research Promotion Headquarters, 2013).
During the 2016 Kumamoto Earthquake, the Takano-Shirahata segment was moved at the begging and the rupture propagated to the Futagawa fault zone in contact with the northern end of this segment. Relatively small aftershock (M<5.5) were occurred within the Hinagu segment, however the magnitude is significantly smaller than the expected earthquake which is M7.5 by using the Matsuda’ s empirical equation (1975) (Earthquake Research Promotion Headquarters, 2013), this indicated that the fault rupture has not been propagated to the Hinagu segment. Therefore, we conducted a trench and boring survey at Minamibeta area in Uki City to investigate the palaeoseismic events at around the central portion of Hinagu segment.
At this location, boring survey (Nuclear Power Engineering Corporation, 1998; Kumamoto Prefecture, 1998a, b; Geological Survey of Japan, 2007) and trench survey (GSJ, 2007 and Yoshioka et al., 2007) have been conducted, although clear faults were not observed on the trench wall. But the lower formations in the trench were inclined to the west direction due to the deformation caused by the fault activity, and they estimated that there was at least one event between 11,000 to 3, 900 years ago, and no fault activity was recognized after 1,800 years ago from the age of the undeformed strata (Yoshioka et al., 2007).
In this research, we dig a trench at a position adjacent to the south side of the trench reported by GSJ (2007) and extending further to the west direction. A clear reverse fault dipping to southeast was appeared on the trench wall and the large-scale flexure of formations was observed around the fault surface. This trench survey is still continuing at the time of the submission of this abstract, and the detailed activity history of the Hinagu segment at the Minamibeta area will give a presentation on that day.

Keywords: Hinagu fault zone, Hinagu segment, Trench survey

The grand deformation detected by new method of InSAR, in the 2016 Kumamoto Earthquake

*Masashi Omata[1], DAISUKE SANGO[1], Yorihide Kohriya[1], Kaoru Taniguchi[1]

1. PASCO CORPORATION

The InSAR results derived from ALOS-2 images, displayed the visualization of large-scale fault motion and surface ruptures. But it is difficult to extract the seismic surface ruptures and correct positioning of the surface rupture using only phase image. We developed a new surface rupture methodology by combining InSAR results, phase image and coherence image, and the terrain representation image. We applied the developed methodology by utilizing ALOS-2 data and created the InSAR results for the 2016 Kumamoto Earthquake and compared the extracted information with the local situation. In MItake Mashiki town, the results shown that the surface rupture detected by this methodology coincided with the surface rupture and strained fields as confirmed by the conducted field survey. But then, in Togawa Mashiki town, there are only cracks on the road at low-coherence zone. After the carefully survey, we discovered broad deformation at the roads and channels.
This method can extract the seismic surface rupture over a wide area. In addition, this method is possible to catch the deformation of the ground level which it's difficult to recognize as the surface rupture.

Keywords: the 2016 Kumamoto Earthquake, InSAR, surface rupture, coherence image, ALOS-2

Geomorphological and Geological Factors of Surface Cracks in Aso-caldera in association with the 2016 Kumamoto Earthquake

*Haeng-Yoong Kim[1], Mizuki Nagai[1], Tsuyoshi Haraguchi[1]

1. Osaka City University, Graduate School of Science, Division of Biology &Geosciences

In The Kumamoto earthquakes of April 14, 2016 (Mw 6.5) and 16 (Mw 7.0), the surface was ruptured by the lateral strike faulting with normal faulting on the eastern half of the Futagawa fault zone and on the northern part of the Hinagu fault zone (Kumahara et al, 2016; AIST, 2016). The length of surface rupture is estimated as 27 km. However, factors of the ground destruction that caused the damage have not been sufficiently elucidated. Clear surface cracks appeared in the northeast - south - western direction in the lowland of the Aso caldera located on the east side of the Futagawa fault zone. Regarding the cause of this crack zone, Lin et al. (2016) and Nakata et al. (2016) assumed an earthquake fault, but Kuroki et al. (2016) said it is due to the lateral movement of the ground. On October 8, 176 days after the main shock, Nakadake wss erupted in Mt. Aso located in the west of the Futagawa fault zone. To clarify the origin of surface cracks in the Aso caldera is extremely significant in understanding the location relationship between active faults and volcanoes. Present study investigated the distribution and displacement pattern of cracks, (2) the geomorphological and geological elements of crack formation fields, and (3) the existence of active fault topography in the Otohime district located in the central part of the crack zone in the caludera. We, then, propose that the cause of the crack is not fault rupture but is by the gravitational mass-movement.

Keywords: Kumamoto Earthquake, Aso-caldera, Cracks, Lateral Mass Movement

Seismic Velocity Structure around Segment Boundary of the Futagawa-Hinagu Fault zone

*Yasuhira Aoyagi[1], Haruo Kimura[1]

1. Central Research Institute of Electric Power Industry

The 2016 Kumamoto earthquake occurred along the Futagawa fault and northern part of the Hinagu fault, Takano-Shirahata segment. All kinds of data, such as crustal deformation, surface rupture distribution, and slip distribution on the source fault associated with the earthquake, indicate that the earthquake fault rupture does not spread to southern, the Hinagu segment. Rupture history prior to this event also shows the difference between the both segments (HERP, 2013). Accordingly the segment boundary has possibly terminated fault rupture as a structural barrier. In order to elucidate the character of seismic velocity structure in the segment boundary, we carried out a seismic tomography analysis using a dense temporary seismic stations. Thirty temporary stations had been deployed from the end of July to early September 2016 in the campaign. The network covers almost all aftershock area with a span of 5 km. We used 1710 earthquakes’ combined arrival time data detected by the temporary stations and also by surrounding permanent stations into the double-difference tomography program, tomoDD (Zhang and Thurber, 2003). As a result, high resolution velocity distribution is acquired in the depth range of 2.5 km to 12.5 km, which is equivalent to seismogenic layer. The largest feature of the results is velocity anomaly stripes trending to ENE-WSW direction. The direction corresponds well with those of Ooita-Kumamoto Tectonic Line and Usuki-Yatsushiro Tectonic Line, therefore the velocity structure probably reflect such large geological structure in this area. Especially ENE-WSW trending velocity anomalies are remarkable over the boundary between the Takano-Shirahata segment (lower velocity) and the Hinagu segment (higher velocity) at all depth layers. The location and the direction of the boundary correspond well with the geological boundary of sedimentary rocks (Mifune sedimentary group) in north and metamorphic rocks in south. Therefore change of physical properties over the geological boundary probably plays a role of a structural barrier to control fault rupture. Similar suggestion has already shown by Matsumoto et al.(2016) based on their gravity anomaly analysis. But it should be noted that 80 % of the 1710 hypocenters locate in a specific range of velocity layer (Vp=5.9-6.3km/s, Vs=3.5-3.8km/s, Vp/Vs=1.62-1.74). Therefore we think the seismogenic layer is another basement rock under the Mifune sedimentary group. Granitic rocks are the most probable material of the seismogenic layer in comparison with laboratory velocity measurements on various rocks under high pressure (Christensen, 1996).

Keywords: Futagawa-Hinagu fault zone, Segment boundary, Seismic velocity structure

Integrated Research for Beppu –Haneyama Fault Zone (East part of Oita Plain –Yufuin Fault) –Research in 2016 - Integrated Research Project for Active Fault Systems of MEXT

*Keiji Takemura[1], Research Group for Beppu –Haneyama Fault Zone (East part of Oita Plain –Yufuin Fault)

1. Beppu Geothermal Researh Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University

<Introduction>

Integrated Research for Beppu –Haneyama Fault Zone (East part of Oita Plain –Yufuin Fault) in central Kyushu started on 2014 during three fiscal years program as one of Integrated Research Project for Active Fault Systems of MEXT. We need more precise study on fault distribution, latest event in and around Beppu Bay region and relationship with western end of Median Tectonic Line for understanding of Beppu –Haneyama Fault Zone.

<Purpose of project>

We carry out geomorphological, geological and geophysical researches on the basis of existing research findings. Obtained new data on geomorphology and geology let us know new findings on precise location and activity of fault in and around Beppu Bay area (Theme 1). Moreover, new geophysical data on subsurface structure indicate size and motion of earthquake fault reached to the earthquake occurrence layer (Theme 2), and we also calculate precisely ground motion on the basis of precise subsurface structure and earthquake fault model (Theme 3).

<Research groups and contents of observation and survey>

Research group consists of about 40 researchers of Kyoto University, Kyushu University, Advanced Industrial Science and Technology and related Institutions, and also three sub-groups on the basis of methodology and science target. Sub-theme group 1: Research on precise location and shape of active fault, and average slip rate and event age. Sub-theme group 2: Research on three dimensional structure and subsurface structure of fault zone and the area. Sub-theme group 3: Research on establishment of subsurface structure model and evaluation of ground motion.

The result during 2016 fiscal year is presented in the session.

Keywords: Beppu –Haneyama Fault Zone, Integrated Research Project, Active fault and subsurface structure, Oita Plain

Thrust-related structural characters of the Morimoto-Togashi Fault revealed by high-resolution shallow seismic reflection profiling

*Tatsuya Ishiyama[1], Naoko Kato[1], Hiroshi Sato[1], Shigeru Toda

1. Earthquake Research Institute, University of Tokyo

We collected ca. 7.3 km long, onshore high-resolution two dimensional (2D) seismic reflection and refraction data across the Morimoto-Togashi Fault, active thrust fault within a failed rift system in the Sea of Japan. The processing of the seismic reflection data underpinned by shallow P-wave velocity structures determined from refraction travel time tomography illuminates the detailed subsurface structure to depth of ca. 3 km. The preliminary interpreted depth-converted section correlated with nearby Neogene stratigraphy indicates moderately east-dipping thrust fault plane overlain by monocline comprised by Plesitocene to Pliocene sedimentary units. We will mainly discuss (1) the shallow structural characteristics of the active thrust based on our interpretation of the 2D seismic data in combination with the Neogene stratigraphy, (2) fault activity based on growth architecture and fold scarp morphology, and (3) and implications for regional tectonic setting especially associated with reactivation of the failed rift zone. In any case this example successfully shows high-resolution 2D seismic reflection imaging with dense and numerous seismic recorders to be a useful tool in defining otherwise inaccessible active blind faults and their recent fault activity.

Keywords: seismic reflection profile, Sea of Japan

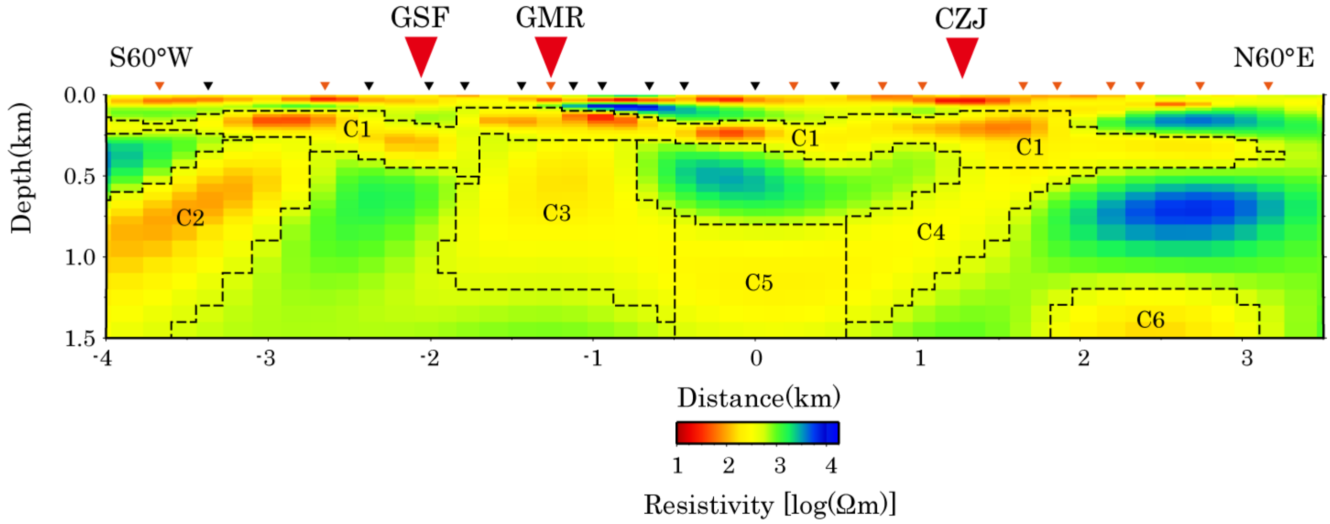
Electrical resistivity structure beneath Gomura fault zone(Go-seihou fault, Gomura fault, Chuzenji Fault)

*Akira Mimura[1], Satoru Yamaguchi[1], Shin Kuramitsu[1], Ko Kozakai[2], Haeng-Yoong Kim[1], Hideki Murakami[3], Shigehiro Katoh[4]

1. Graduate School of Science, Osaka City University, 2. Faculty of Science, Osaka City University, 3. Research and Education Faculty, Kochi University, 4. Hyogo Museum of Nature and Human Activities

The Gomura fault zone is located in the Tango Peninsula, Koto, Japan, and consists of the Go-seihou fault, the Gomura fault and the Chuzenji fault. They run closely (within 3km) and nearly parallel to each other. These faults have different features in fault activity (e.g., mean slip rate, cumulative displacement). The Go-seihou fault shows no clear displacement at the surface. The last faulting event of the Gomura fault is 1927 Kita-Tango earthquakes, while that of the Chuzenji fault is estimated to be about 10 thousand years ago. Cumulative displacement of the Chuzenji fault is about twice larger than the Gomura fault.
Clear electrical resistivity variation is expected to be identifiable in the vicinity of an active fault as a result of enriched and interconnected fluid (meteoric waters and/or groundwater) in fractures and/or uneven fluid distribution across the fault because of impeded cross-fault fluid flow. It is expected that special extent and resistivity contrast to surrounding area. It is interesting to reveal relationship among width of conductive zone and futures of the fault in fault activity.
Aiming to clarify the above relationship, we made an Audio frequency Magnetotelluric (AMT) survey at 25 sites including 12 sites by Ouchi (2014) along the transect (7km) across the surface trace of the Gomura fault zone. We established the two-dimensional resistivity model (GCH model) along the transect.
The GCH model is characterized by six conductive zone (C1 –C6). Region C1 is shallow and sub-horizontal layer. We interpret the layer is caused by meteoric water and/or groundwater included in the highly weathered granite layer on a fresh granite layer by comparing our model and the electrical logging data at the 1300m borehole near our survey line. Region C3 and C4 are located beneath the Gomura and Chuzenji faults, respectively. Former region is wider than latter region. We can say these regions are caused by fluid in the damage zones formed by fault movement. It is interesting that no conductive region is detected beneath the Go-seihou fault.

Keywords: The Gomura Fault, electrical resistivity structure, Damage zone


GSF
GMR
CZJ
S60°W
N60°E
Depth(km)
0.0
0.5
1.0
1.5
C1
C1
C1
C2
C3
C4
C5
C6
-4
-3
-2
-1
0
1
2
3
Distance(km)
1
2
3
4
Resistivity [log(Ωm)]

Resistivity structure beneath the southeastern part of the Yamasaki fault zone, southwest Japan

Shin Kuramitsu[1], *Satoru Yamaguchi[1], Yusuke Oda[1], Shuhei Ito[1], Akira Mimura[1], Hideki Murakami[2], Shigehiro Katoh[3], Makoto Uyeshima[4]

1. Department of Geosciences, Graduate School of Science, Osaka City University, 2. Research and Education Faculty,Kochi University, 3. Division of Natual Histoy, Hyogo Museum of Natue and Human Activities, 4. Earthquake Research Institute, Tokyo University

The Yamasaki fault zone (YFZ) consists of the Nagisen fault, the main part of the YFZ, and the Kusadani fault. The main part of the YFZ is further divided into a northwestern (NW) group (the Ohara, Hijima, Yasutomi, and Kuresakatouge faults) and a southeastern (SE) group (the Biwako and Miki faults) based on their latest faulting events and mean slip rates; AD 868 and 1.0 m/kyr for the NW group vs. AD400 - 600 and 0.8 m/kyr for the SE group (Okada, 1987; Earthquake Research Committee, 2013). The Biwako fault consists of the western trace (A) and eastern trace (B) (Okada and Togo, 2010).
Magnetotelluric methods are powerful methods of surveying the subsurface structure of active faults as characteristic electrical conductivity variations are expected around an active fault. Among available methods, the audio-frequency magnetotelluric (AMT) method is useful because of its high spatial resolution for the depth range concerned.
Aiming to reveal conductivity structure beneath each fault and relationship between them, many AMT surveys have been made along transects across the main part of the YFZ, that is 81 stations along seven survey lines for the NW group and at only 29 stations along two survey lines for the SE group. It is clear that more observation is necessary to clarify features of resistivity structure below whole SE group.
We made an AMT survey along the line across the trace B of the Biwako fault where is between the trace A and the Miki fault and established the 2-D resistivity model along the line (BWK_B model). Further, we reanalyzed the data along MIKI line and establish the new 2D resistivity model (MIKI model).
In this paper, we explain features of the BWK_B and MIKI models, then show variation of the resistivity structure along the SE group, finally, interpret them by taking into geological structure and other geophysical information (Bouguer anomaly and seismological survey).

Details of observation, data analysis, and modeling process are shown blow.

Observation

AMT surveys were undertaken in February 2015 and March 2016 at 24 stations along the line (BWK_B line) at 24 stations along the line across the trace B of the Biwako fault. Two horizontal components of electrical field and three components of magnetic field were measured at each station. The remote station of the magnetic field was made ~18km north from the northeastern end of the BWK_B line.

Analysis

After MT response functions were obtained according to the remote reference method (Gamble *et al.*, 1978), we estimated dimensionality below the study area and strike of resistivity structure if structure is estimated to be two-dimensional. Then the two-dimensional resistivity model was constructed using the code of Ogawa and Uchida (1996). Ultimately, we established the BWK_B and MIKI models.

Keywords: Yamasaki fault zone, active fault, Magnetotelluric method, resistivity structure

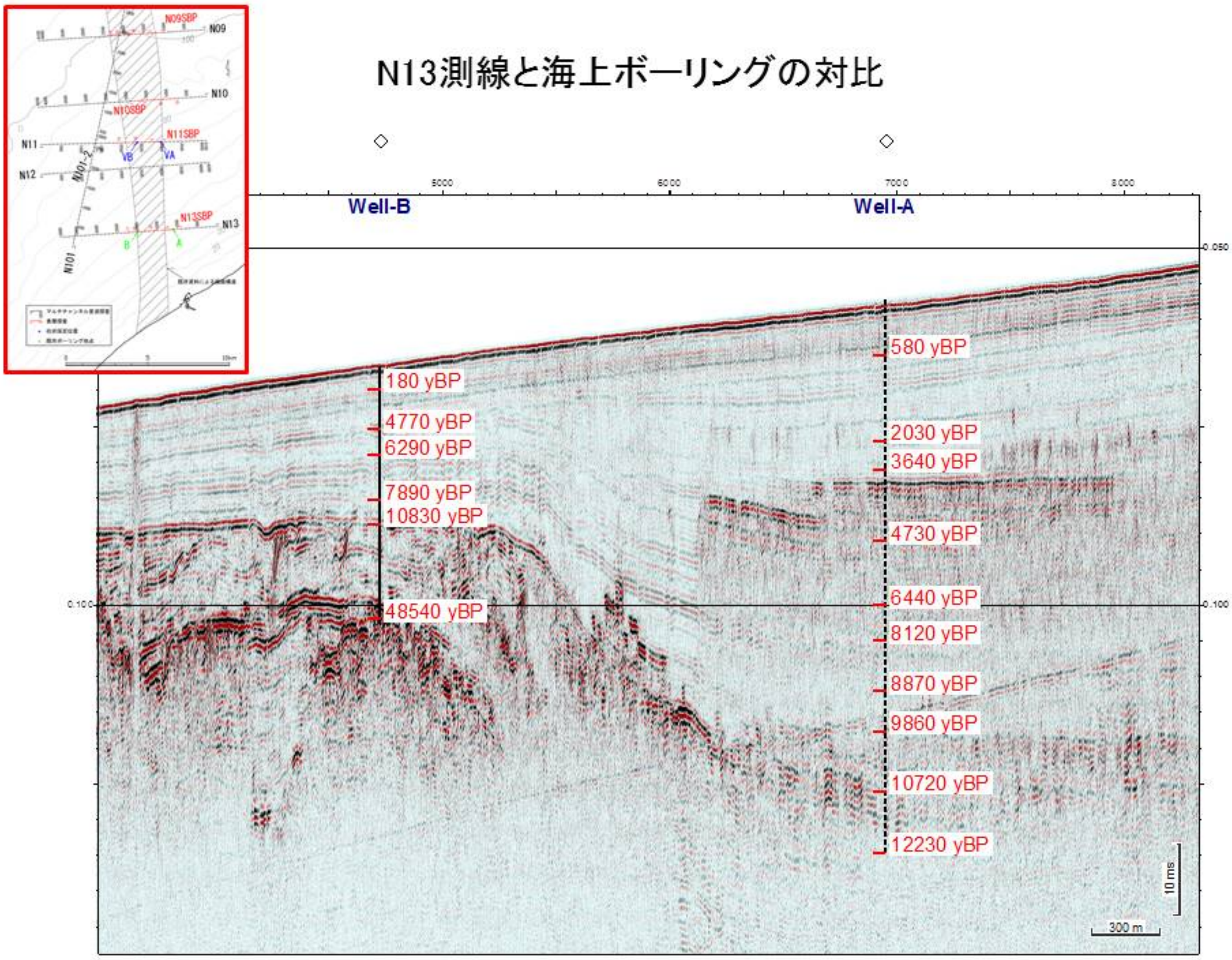
Spatial distribution of active structure and the activity in the offshore extension of the Nagaoka-Heiya-Seien Fault zone.

*Shintaro Abe[1], Takashi OGAMI[2], Hiroshi Mori[3], Kenjiro Mukaiyama[4], Naohiro Kazui[4]

1. Advanced Industrial Science and Technology, 2. Chuo Univ., 3. Shinshu Univ., 4. Kawasaki Geological Engineering Co.,Ltd

We conducted offshore active-fault survey on the offshore extension of the Nagaoka-Heiya-Seien Fault zone. We obtained high-resolution multi-channel seismic reflection data (150 km total length) and 2 sedimentary cores. Existing survey data are also examined in this study.
Results of the seismic reflection survey revealed distinctive subsurface flexure structure along the fault zone. The subsurface structure extends to an uplift bulge (lying NE-SE), and fades out. We recognized surface deformations at several areas, and they possibly indicate the latest event.
We investigated recent sedimentary record based on the newly obtained cores and existing submarine borehole logs. We also reconstructed age-depth curves for the cores based on radiocarbon dating. Sedimentation rates at the footwall(subsiding) side excess those at the hanging-wall(uplifting) side. We calculated averaged vertical
deformation rate as 3.8 m/ky based on both the seismic profiles and the age-depth curves.

Keywords: the Nagaoka-Heiya-Seien Fault zone, active structure, high-resolution seismic reflection survey



N13測線と海上ボーリングの対比
N09SBP
N09
N10
N10SBP
N11
N11SBP
VB
VA
N12
N101-2
N13SBP
N13
N101
5000
6000
7000
8000
Well-B
Well-A
180 yBP
4770 yBP
6290 yBP
7890 yBP
10830 yBP
48540 yBP
580 yBP
2030 yBP
3640 yBP
4730 yBP
6440 yBP
8120 yBP
8870 yBP
9860 yBP
10720 yBP
12230 yBP
10 ms
300 m

Late Quaternary Slip Rates and Recurrence Interval on the Median Tectonic Line Active Fault Zone in the Eastern Shikoku, Southwest Japan

*Hideaki Goto[1]

1. Graduate school of letters, Hiroshima University

The Median Tectonic Line (MTL) active fault zone extends for about 190 km through Shikoku, southwest Japan. Though the MTL is the most significant onshore active tectonic feature in southwest Japan, its Late Quaternary slip rate has been estimated at only a few locations with reasonable references and age. Better information on this feature's recent slip rates is critical to understanding the ongoing tectonic processes in the region and evaluating the seismic risk of this fault system. In this paper, new estimates of the Late Quaternary slip rate are reported from the Ikeda and Chichio faults in the central portion of the MTL. The author mapped offset Late Pleistocene fluvial terrace surfaces and risers and dated them using tephrochronology and radiocarbon dating. The slip vectors of both faults are very similar, as derived from piercing points on the terraces' inner edges. The vertical component of displacement is 8–10% of the horizontal component. Long-term slip rates during the Late Quaternary were calculated as 7.8–9.1 mm/yr, which is more precise than previous studies and represents the highest slip rate in the MTL. This rate is also much faster than previously reported short-term slip rates of elastic strain storage. Based on the amount of slip associated with the most recent surface rupture along the Chichio fault (6-7m; Okada and Tsutsumi, 1997) and the calculated right-lateral slip rate (7.8–9.1 mm/yr) in this study, the recurrence interval was estimated to be about 660–900 years.

Keywords: active fault, geomorphology, slip rate, digital elevation model, Median Tectonic Line, southwest Japan

Tectonic events recorded in the varved sediments of Lake Suigetsu, Fukui, central Japan

*Keitaro Yamada[1], Takeshi Nakagawa[2], Richard A. Staff[3,4], Ikuko Kitaba[2], Junko Kitagawa[5]

1. Graduate School of Science,Kyoto University, 2. Research Centre for Palaeoclimatology, Ritsumeikan University, 3. Oxford University, 4. University of Glasgow, 5. Fukui Prefectural Satoyama-Satoumi Research Institute

Lake Suigetsu, Fukui prefecture, central Japan, is one of 5 tectonic lakes located in the San’ en triangle (e.g. Okada et al., 2010) partitioned by the Mikata and Hiruga Faults of the Mikata Fault Zone in a north-south direction and the Kumagawa Fault in a west-east direction (Nakata and Imaizumi, 2002; Okada, 2012). Lake Suigetsu preserves annually laminated sediments over the last ca.70 kyr (Nakagawa et al., 2012) with a significant number of event layers (Schlolaut et al., 2014). The sediment is one of the best-dated annually laminated materials in the world (e.g. Staff et al., 2011; Bronk Ramsey et al., 2012). Theoretically, the sediments have the potential to provide one of the most precise and highly resolved records of tectonic events in the world. In this study, we reconstructed a very detailed history of fault movements from changes of sedimentation rate in off-fault records using the new core drilled in 2014 (SG14) and the previously obtained and well-dated core (SG06).

The SG14 core was obtained from a point ~320 m to the east of the SG06 coring site funded by the Fukui Prefecture. The SG14 core is composed of overlapping segments recovered from four nearby boreholes to ensure continuity of the whole archive. We also took high-resolution photographs of the sediment section on the coring site before any oxidation could take place. On the basis of these high-resolution photographs, we recognised more than 300 event layers in the SG14 core and precisely correlated them to their counterparts in the SG06 core. This enabled us to transfer the high-quality SG06 chronology to the SG14 core and compare sedimentation rate changes of both cores in an exceptionally high resolution and precision for the last ca. 50 ka.

The result showed semi-cyclic step changes in the difference of the sedimentation rate at least three times over 50,000 years. That is, the relative sedimentation rate drastically increased at the eastern side of the lake, closest to the fault (SG14), after gradually increasing at the western side near the depositional centre of Lake Suigetsu (SG06). These cyclic step shifts were not synchronous with thick and very characteristic event layers such as turbidites. These findings suggest that: (i) the cyclic step changes in differential sedimentation rate demonstrate direct records of the deformation events due to slips of the Hiruga Fault, and (ii) much thicker turbidites that are seen in the lake’ s sediment (at least not all of them) were not always induced by the near fault’ s movement.

We propose that the following sequence best explains the mechanism responsible for these subtle changes in sedimentation rates: 1. the eastern side of the lake was lifted relatively, due to a reverse-fault slip of the Hiruga Fault; 2. the sedimentation rate increased relatively at the eastern site of SG14 because of sediment focusing nearer the fault; 3. subsequently, the sediment focusing occurred further from the fault; 4. the sedimentation rate gradually increased at the western SG06 coring site located near the lake’ s depocentre; 5. the eastern site (SG14) was relatively lifted by the fault again, and the same sequence repeated for a number of times. These results are consistent with the subsidence events related to the activity of the Mikata Fault Zone estimated in the nearby Lake Mikata, located to the south of Lake Suigetsu (Ishimura et al., 2010). In summary, we have reconstructed a precise and highly resolved record of fault movements. The detailed ages as well as the typical recurrence period will be reported at this conference.

Keywords: Lake Suigetsu, Sedimentation rate, tectonic event, varved sediments

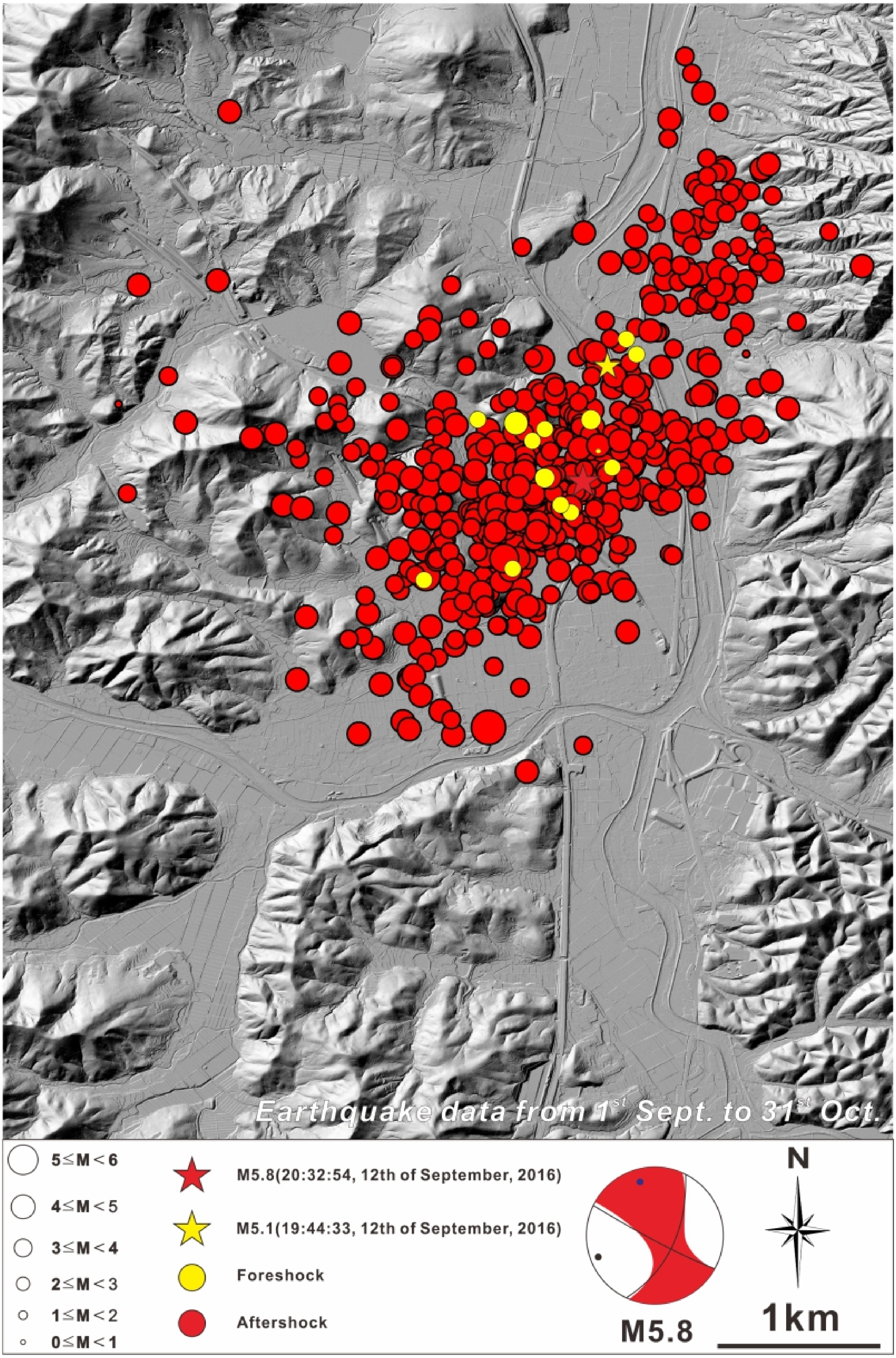
Preliminary study on related faults and triggering mechanism of the 9.12 Gyeongju earthquake (ML=5.8)

*Taehyung Kim[1], Junho Lee[1], Young-Seog Kim[1]

1. Dept. of Earth & Environmental Sciences, School of Earth Environmental Hazard System Science, Pukyoung National University

The 9.12 Gyeongju Earthquake (ML=5.8), the biggest instrumental earthquake in South Korea, are followed by hundreds of small to medium magnitude of aftershocks around the Hwagok reservoir in Naenam-myeon, Gyeongju, Korea. This earthquake is a shock to Korean people who believed that a Korean peninsula is a safe place from earthquakes. It was enough people to think the importance of earthquake and active fault. One of the hottest issues after the earthquake is the related active fault. We directly visited the epicenter area and carried out field work to find surface ruptures or any related faults, and furthermore, we have done lineament analysis based on pre-existing satellite images and new LiDAR data as well as fore/aftershocks distribution. Although we could not find any surface ruptures related to this earthquake, there are many N-S to NNE-SSW trending lineaments and minor dextral faults, which are parallel to the main Yangsan Fault and a subsidiary Deokcheon fault. The two major faults are geometrically linked by several NE-SW trending connecting lineaments in LiDAR Image. Focal mechanisms of the 9.12 Gyeongju Earthquake represent NNE trending dextral strike-slip fault, and distributions of fore/aftershocks indicate the concentration in the linking damage zone between the two major faults. Based on these preliminary studies, the 9.12 Gyeongju Earthquake may be triggered by a connecting fault in the linking damage zone of the two NNE-SSW trending faults (Yangsan fault and Deokcheon fault) with a dextral strike-slip sense.

Keywords: Gyeongju Earthquake, Active fault, Earthquake mechanism, LiDAR, Aftershock distribution, Fault damage zone


Earthquake data from 1st Sept. to 31st Oct.
5≤M<6
4≤M<5
3≤M<4
2≤M<3
1≤M<2
0≤M<1
M5.8(20:32:54, 12th of September, 2016)
M5.1(19:44:33, 12th of September, 2016)
Foreshock
Aftershock
M5.8
N
1km

Occurrence probability and frequency of large (Mj6.8) earthquakes on active faults in Japan

*Hisao Kondo[1], Kazuhiro Iwakiri[2], Hirota Tani[3], Kenji Satake[4]

1. Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 2. Japan Meteorological Agency (JMA), 3. Earthquake and Disaster-Reduction Division, MEXT, 4. Earthquake Research Institute, The University of Tokyo

The 2016 Kumamoto earthquake (Mj 7.3; Japan Meteorological Agency magnitude) caused devastating damages and more than 180 casualties. It occurred in an active fault zone and surface ruptures appeared mostly along the previously mapped active faults (The Headquarters for Earthquake Research Promotion-HERP, 2016). The source fault was a part of the Futagawa fault zone that has been evaluated for long-term forecast of destructive earthquake occurrence in Japan (HERP, 2002; 2013). The Mj 7.3 earthquake was the first case, after the 1995 Kobe earthquake, that characteristic earthquake with surface rupture occurred on the major active fault zone evaluated by HERP. It coincides with the past estimation of the average occurrence interval of 10-20 years of an earthquake on those active faults in Japan (Secretariat of HERP, 2001). Meanwhile, the occurrence of large (Mj6.8) earthquakes on minor active faults has been more frequent in recent years.

Under these circumstances, we re-examined the frequency and probabilities of large (Mj6.8) earthquakes on active faults in the last 125 years. In order to classify the damaging earthquakes on active faults, we used the catalogue of damaging earthquakes in Japan (Usami et al., 2013) and previously evaluated reports by HERP.
In total, 28 large (Mj6.8) damaging crustal earthquakes occurred in the last 125 years, and 22 of them (80 %) are related with mapped active faults, and 6 (20 %) are not. The 22 earthquakes in 125 years yield the average recurrence interval of 5.7 years. Using the individual recurrence intervals, 4.6+/-3.7 years is obtained for all large (Mj6.8) damaging earthquakes and 6.0+/-5.5 years for those on active faults. These estimates clearly show shorter recurrence intervals than the previous estimation made in 2001.

We also examined the frequency distribution of recurrence intervals of all the large (Mj6.8) damaging earthquakes. The distribution shows a bimodal distribution consisting of two groups: one <6 years and another >8 years. The average recurrence interval of the former group is 2.9+/-1.5 years, which is extremely short in comparison with the average recurrence interval in the last 125 years. The longest interval in the latter group is 17 years between the 1978 Izu-Oshima-Kinkai earthquake and the 1995 Kobe earthquake. It is thus apparent that the occurrence of the Mj6.8 damaging earthquakes exhibits the temporal clustering and long quiescence periods.
Under the assumption of Poisson process, we then calculated the earthquake probability within the next 5, 10 and 30 years for entire Japan. We obtained 72%, 92%, 100% probabilities for all Mj6.8 damaging earthquakes, and 62%, 86%, 99.7% for active fault earthquakes, respectively. Assuming the present day is within a clustering period, the probability increases up to 68-97% within the next 5 years.

We further investigated the temporal clustering and the timing of mega-thrust earthquakes along the subduction zones. In northeastern Japan, 5 active fault earthquakes occurred within 5 years before and after the 2011 Tohoku earthquake. In southwestern Japan, 3 active fault earthquakes occurred within 5 years before and after the 1944 Tonankai and 1946 Nankai earthquakes. These frequencies are comparable with the average recurrence interval of 2.9+-1.5 years for the above-mentioned <6 years

group. This result is in accord with the previously known idea that inland crustal earthquakes increase before and after the occurrence of mega-thrust earthquakes along the subduction zones, although the above probability is computed with the assumption of Poisson process, hence it is time-independent. We can reasonably expect the occurrence of a few active fault earthquakes before the upcoming Nankai earthquake, probably 3 to 5 active fault earthquakes. To forecast them more accurately, the earthquake probability based on the BPT model for individual active faults and time-dependent seismic hazard assessment are necessary.

Application of the 3D geological structure analytical technique to sea section in the Hinagu Fault Zone

*Masatoshi Yagi[1], Izumi Sakamoto[1], Yuka Yokoyama[1], mikio fujimaki[1], Hiromichi Tanaka[1], Omer Aydan[2], Kenji Nemoto[1]

1. Tokai University, 2. Ryukyu University

Hinagu Fault Zone extends from the Aso volcano to the Yatsushiro-sea. In the Yatsushiro-sea, some seismic surveys were carried out so far, and clarified distribution of a number of submarine fault group (the fault group called Yatsushiro-sea Submarine Fault Group). The Headquarters for Earthquake Research Promotion (2013) estimated the probability (0-16%) of the Yatsushiro-sea Submarine Fault Group triggering an M7.3 earthquake within the next 30 years. However, the activities and amount of displacement (vertical and horizontal) are not understood well. Tokai University conducted, as part of MEXT 2010 nearshore active fault survey project, a high-resolution single-channel seismic survey using parametric sub-bottom profiler for confirm a deformation structures and distribution of them. We continued investigating it continuously after the project. In this study, we tried 3D geological structure analytical technique for detecting not only vertical displacement but also horizontal displacement.
We observed drag deformation which is suggests to the existence of strike-slip fault in seismic profile at Northeastern part of the fault group (tentatively as A area). We applied the technique using a lot of seismic profile (survey interval is 20-50m) to the A area. On surfaces which formed in about 20,000 y.B.P and about 13,000 y.B.P, we observed subsidence area located in Northwest side of main fault. The subsidence area is gradually slow down depth to the southeast like a stairs. The feature is similar to ground surface displacement which observed by GEONET and ALOS-2/PALSAR-2 interferometric SAR of the 2016 Kumamoto Earthquake. The scale is different but the feature similarity suggests Yatsushiro-sea Submarine Fault Group has strike-slip component. There are three valleys in the subsidence area extend NW to SE direction, and these are right laterally displaced. Based on the formation age of the surface, we estimate the mean laterally slip rate 2.1-4.5m/ky. However, the slip rate is higher than land fault (Hinagu Fault: slip rate 0.7m/ky). So, the slip rate is still under consideration

Keywords: Hinagu Fault Zone, Yatsushiro-sea Submarine Fault Group, Seismic Trenching, Strike-slip fault

An outcrop showing recent cumulative slip on a normal fault co-ruptured with the Futagawa fault at the 2016 Kumamoto earthquake

*Takahashi Naoya[1], Shinji Toda[2], Daisuke Ishimura[3]

1. Department of EarthScience, Tohoku University, 2. International Research Institute for Disaster Science, Tohoku University, 3. Department of Geography, Tokyo Metropolitan University

The 16 April 2016 Mw = 7.0 Kumamoto earthquake accompanied ~31-km-long surface rupture along the NE part of the Hinagu fault and the Futagawa fault (Kumahara et al, 2016). The surface rupture zone along the Futagawa fault mostly exposed right-lateral strike slip up to 2 m. A unique feature of the 2016 surface rupture is an ~10-km-long normal faulting surface rupture with a maximum of 2-m vertical separation mostly along the previously mapped Idenokuchi fault located 1-2 km south of and sub-paralleled to the Futagawa fault.
Here we report an outcrop at the normal faulting surface rupture at the riverbed of Kanayama river which runs through Shimojin, Mashiki City. The site is located 300-m south-east of the Futagawa fault and a 50-60 cm normal coseismic slip occurred at the 2016 Kumamoto earthquake. Although we only had a brief time to observe this outcrop due to levee wall construction, we observed a normal fault (f1) which was responsible for the 16 April earthquake and recent gravel units (Fig. 1). Along the f1 strand, the top of bedrock shows about 2.5 m of vertical separation that corresponds to roughly four or five times the amount of coseismic vertical separation. It allows us to infer that there have been several earthquakes that the normal fault have ruptured together with the Futagawa fault simultaneously.

Keywords: Active fault, Surface rupture, 2016 Kumamoto earthquake

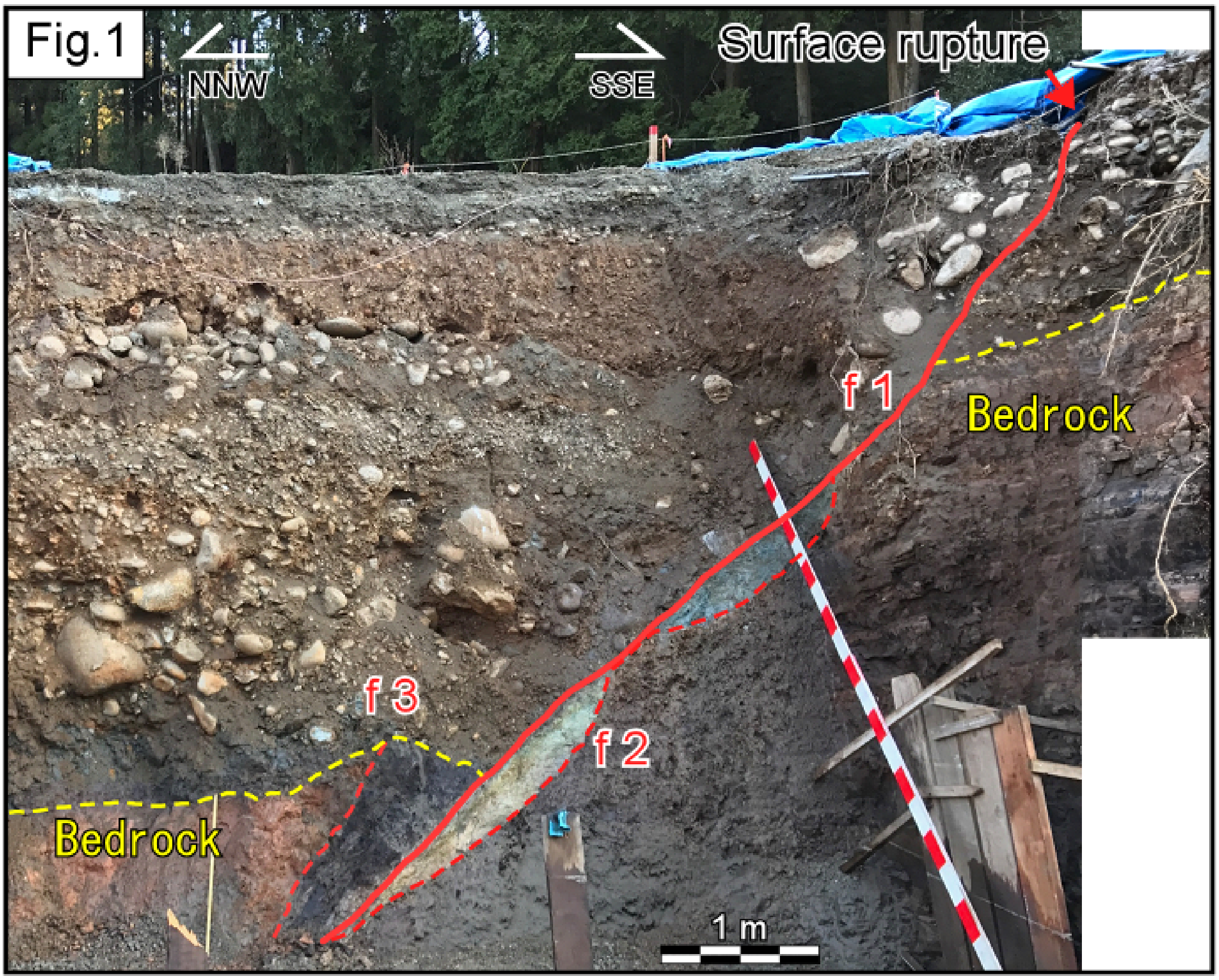


Fig.1
NNW
SSE
Surface rupture
f 1
Bedrock
f 3
f 2
Bedrock
1 m

The surface rapture of the 2014 Northern Nagano Earthquake detected by InSAR

*Yorihide Kohriya[1], Masashi Omata[1], DAISUKE SANGO[1], Noriyuki Shibuya[1]

1. PASCO CORPORATION

The DInSAR results (phase image and coherence image) derived from the sateraite images, displayed the visualization of large-scale fault motion and surface ruptures.
Since there is no blurring or terrain information interpreted on the image, it is difficult to extract the seismic surface ruptures and correct positioning of the surface rupture using only two images.
We developed a new surface rupture methodology by combining DInSAR result and the terrain representation image.
We applied the developed methodology by utilizing ALOS-2 data and created the DInSAR results for the past 2014 Northern Nagano Prefecture Earthquake and compared the extracted information with the local situation.
We confirmed intermittent surface ruptures from Shiroyama to Horinouchi in Hakuba village.
In Horinouchi, although broad flexural deformation appeared, the amount of deformation was small and mapping was difficult. The image was able to show this deformation area.
The present paper describes that the developed methodology could extract the seismic surface rupture over a wide area quickly, and demonstrated the potential mapping effectiveness as well.

Keywords: DInSAR, Surface rupture, 2014 Northern Nagano Prefecture Earthquake

Postseismic deformation extracted by InSAR, after the 2014 Northern Nagano Prefecture Earthquake

*Masashi Omata[1], DAISUKE SANGO[1], Yorihide Kohriya[1], Noriyuki Shibuya[1]

1. PASCO CORPORATION

The 2014 Northern Nagano Prefecture Earthquake (Mj 6.7) occurred in November 22, 2014. The crustal deformation emerged in 30km*30km area by the InSAR analysis data after the earthquake (GSI, 2015). And, the surface ruptures occurred 9 kilometers from Shiojima Hakuba village to Higashisano along the Kamishiro fault (Okada et al., 2015). The relation between the appearance position of surface ruptures and the discontinuities of interference phase on the InSAR imagery was studied (Nakano, 2015).
We created InSAR phase image from ALOS-2 data after the 2014 Northern Nagano Prefecture Earthquake. The data is pair of 28 November 2014 and 26 June 2015. As a result of the analysis, the east side of surface rupture moved to the west or went to up. The amount of deformation is 3-4cm in the direction approaching a satellite.

Keywords: the 2014 Northern Nagano Prefecture Earthquake, InSAR, Postseismic deformation, Kamishiro fault, surface rupture, ALOS-2

Historical earthquakes have altered age distributions of stone lanterns in temples and shrines in Japan

*Mamoru Kato[1]

1. Graduate School of Human and Environmental Studies Kyoto University

Strong ground motion often topples stone lanterns, which are small stone objects standing in precincts of Japanese temples and shrines. For example, stone lanterns at Zenkoji Temple, Nagano, were severely damaged by the earthquake on 2014 Nov 22 in northern Nagano. Similar damage were recorded in historical documents, and seismologists use them to learn spatial distribution of shaking and to estimate the source fault. Date of dedication, or built, is often engraved on the column of stone lantern and we can determine ages of stone lanterns, and judging from the ages, older one were apparently survivors of past earthquakes. Stone lanterns are therefore records of historical earthquakes. How (or if) these earthquake are imprinted on groups of stone lanterns was not intensively investigated in the past. In this presentation we summarize our own surveys of stone lanterns at Kitano-Tenmangu Shrine, Kyoto, Iwashimizu-Hachimangu Shrine, Yawata, and Zenkoji Temple, Nagano, and argue whether stone lanterns literarily record historical earthquakes. These three sites are known for historical large earthquakes and a large numbers of stone lanterns in their small precincts. Age distributions of stone lanterns are mainly affected by anthropogenic or religious acts, and evaluation of these effects is necessary before we identify effects of earthquakes. We conclude that historical earthquakes likely have a weak but identifiable imprints on age distributions of stone lanterns. There are a few cases that large earthquakes apparently reset age distribution stone lanterns, suggesting large damages at the specific sites. Stone lanterns in the precincts apparently increases within 10 years of the earthquake, indicating the recovery stage of the community. On the other hand, it is hard to elucidate characteristics of historical ground motion solely from stone lanterns, and role of these items in studying historical earthquakes could be auxiliary to document records.

Keywords: historical earthquakes, storong ground motion

Seismicity on Okinawa Island around 1858, estimated from observations by a French missionary

Takuma Oda[1], *Mamoru Nakamura[1]

1. Faculty of Science, University of the Ryukyus

In the middle of the 19th century, people from western countries visited the Ryukyu Islands to initiate trade with the Ryukyu Kingdom. Some of these visitors carried out weather and earthquake observations while staying on Okinawa Island, especially at Naha. Their records reveal details of historical earthquakes that were otherwise poorly recorded in the Ryukyu Kingdom era. Louis Furet, a French Missionary, visited Naha from 1857 to 1860, and undertook weather and earthquake observations at Naha during this period. The records were in French, and have now been published by Demarée et al. (2016). Using these records, we analyzed the seismicity in Naha from 1857 to 1860.
The occurrence times and intensities of earthquakes were recorded, and the intensity categorized according to the severity of the shaking as “la secousse”, “légère secousse”, “forte secousse”, “violente secousse”, and “secousse assez forte”. In one event, the shaking was recorded as “Secousse assez forte” and was so strong that cracks appeared in the houses. In this case, we estimated the seismic intensity as 5 (Japanese seismic intensity scale). When the shaking was recorded as ”Secousse assez forte” but the damage was not recorded, we set the seismic intensity to 4. Then we set ”violente secousse”, ”forte secousse”, ”la secousse”, and ”légère secousse” to seismic intensities of 3, 2, 1, and 1, respectively.
Next we estimated the epicentral distances and magnitudes of the earthquakes, using the durations of the shaking and the seismic intensity. The recorded durations of 6 events ranged from approximately 60 s to 120 s. The theoretical seismic intensity was calculated using the equation by Si & Midorikawa (1999). The duration of the ground shaking was calculated using the equation by Nojima (2014), which uses the magnitude of the event and the epicentral distance, and calculates the timespan within the seismic intensity was above the specified threshold.
The results show that seven earthquakes with seismic intensities greater than 3 were observed in 1858. In the observations by the Okinawa Meteorological Observatory at Naha, since 1923, there have been only 4 occasions when seismic intensities over 3 were observed 3 times or more within a year. Moreover, there were no years in which seismic intensities of 3 or more were recorded 7 times in a year. This suggests that the seismic activity in 1858 was very high compared with that during the last 90 years.
Moreover, for three earthquakes that occurred from September 22, 1858, to November 7, 1858, we estimated the epicentral distances and magnitudes to be 50-100 km and 5.5-6.5, respectively. These suggest that the swarm activity from September to December accompanied the maximum magnitude of class 5-6 earthquakes, which occurred far from Okinawa Island when Furet was staying at Naha.

Keywords: Okinawa, seismicity, earthquake swarm

Seismic reflection profiling survey across the eastern foot of Tsugaru Mountains

Kyoko Kagohara[1], *Tomoo Echigo[2], Shinsuke Okada[3], Shigeru Toda[4], Naoto Inoue[2], Takahiro Miyauchi[5], Toshifumi Imaizumi[6], Hideki Kosaka[7], Atsushi Miwa[8], Susumu Sakashita[8], Yoshikazu Matsubara[8], Kohei Abe[8], Hideki Kurosawa[8], Nobuhisa Matsuta[9], Tatsuya Ishiyama[10]

1. Yamaguchi Univ., 2. GRI, 3. IRIDeS, Tohoku Univ., 4. Aichi Univ. of Education, 5. Graduate School of Science Chiba Univ., 6. Graduate School of Science Tohoku Univ., 7. Kankyo-Chishitsu Co. Ltd., 8. OYO Corporation, 9. Okayama Univ., 10. ERI, Univ of Tokyo

Fault segmentation is an important issue in predicting the magnitude of an earthquake. To address the issue, we are conducting a comprehensive research in the Tsugaru Mountains and surrounding areas at the northernmost of Honshu. The Tsugaru Peninsula consists of the NS˜NNW-SSE extending Tsugaru Mountains (about 50 km-long, 10 -15 km-wide) and the hills and lowlands. As a fault zone related to the formation of the Tsugaru Mountains, there are the Tsugaru fault, the Aomoriwan-Seigan Fault zone, the Tsugaru-Sanchi-Seien Fault zone. It is considered that asymmetric shape of the Tsugaru Mountains was formed due to uplift and shortening accompanying these fault activities. However, compared with the scale of the mountainous area, the range where the active fault is recognized is short, there is also the possibility of extending further north. On the other hand, on the southern side of the Tairadate Mountains, hills with constant height spread to Sotogahama and Yomogita. The Negishi-Seihou Fault existing eastern portion of Tairadate Mountains may also be continuous to the south (including the marine area). Thus, although there are few known active faults in Yomogita Town to Sotogahama Town in the eastern foot of the Tsugaru Mountains, considering the possibility that the active structure may be blind in the vicinity of Yomogita. Therefore, we conducted a seismic reflection profiling along the Amida River in Yomogita Town, about 7.6 km-long, to define the subsurface structure of the area. In seismic lines, the vibrator truck (IVI ENVIRO VIBE) is used as the seismic source. Source and geophone spacing are 10-m. Seismic reflection data was processed by using the standard CMP stacking method. In this presentation we demonstrate the subsurface structure revealed by the seismic reflection survey

Keywords: Tsugaru Mountains, seismic reflection profiling, subsurface structure, blind thrust

Segmentation of the Kitakami Lowland western marginal fault zone, northeast Honshu, Japan

*Yuma Iwatsuki[1], Shin Koshiya[1], Hiroshi Sato[2], Tatsuya Ishiyama[2], Naoko Kato[2], Yuuki Hashimoto[1]

1. Iwate University, 2. ERI, Univ. of Tokyo

The western marginal faults of the Kitakami Lowland constitute an active fault zone extending almost north to south from the west side of Yahaba to the south of Isawa in Iwate Prefecture consists of various faults such as Uwandaira fault and Detana faults. They have been believed to originate from normal faults caused by E-W extensional stress field during middle Miocene, and to activate as reverse faults under E-W compressional stress field since Pliocene. Several researches have been done so far, but it is not yet clear how the underground geological structure continues. We have inferred a two dimensional subsurface density structures by gravity survey, and have proposed interpreted geological structure along several survey lines, in and around the Kitakami Lowland western marginal fault zone. In this paper, we attempt to clarify the structural continuity of the zone by synthesized these data.
The gravity surveys were conducted along four survey lines trending E-W, which are named from the south to the north, Isawa(59 km long), Kanegasaki(12 km long), Geto(9 km long), Waga(12 km long). In the ‘Mizusawa survey line’, we use Lacoste-Ronberg type gravimeter owned by Earth Science Research Institute, and in other lines, we conducted gravity survey with a Sintrex gravity meter CG-5. The typical interval of observation sites is 200 m. The elevation of the observation sites was surveyed with RTK-GPS. We assumed that the density for Bouguer and terrain corrections were 2.2 g/cm^3.
For the Mizusawa, Waga, and Kanagasaki survey lines, a density structure model was created in consideration of the reflection seismic section. For all line, three layers with different densities were assumed, and the density of the third layer corresponding to the basement rock was 2.7 g / cm^3. As a result of comparison under the above conditions, the inferred geological sections along the Geto and Waga lines, and those along the Kanegasaki and Mizusawa lines showed continuity. In the former areas, there are two half-grabens whose boundary fault in the eastern margins are inverted to reactivate as thrusts. In each of the latter, areas there is one half graben, with a reactivated boundary fault. Therefore we conclude that there is the segment boundary of the Kitakami Lowland western marginal fault zone between Geto-Waga and the Kanegasaki-Mizusawa area.

Keywords: the Kitakami Lowland western marginal fault zone

Tectonic geomorphology of the northeastern Musashino Upland, central Japan

*Tatsuya Ishiyama[1], Daisuke Hirouchi[2]

1. Earthquake Research Institute, University of Tokyo, 2. Department of Geography, Faculty of Education, Shinshu University

We present geomorphic evidence for active faulting and folding found in the northeastern Musashino Upland to define locations, distributions, and recent activity of underlying blind thrust faults. In this region, we recognized geomorphic evidence including pairs of east-facing fold scarps that deform middle to late Pleistocene fluvial terrace deposits. At several locations, these geomorphic scarps are underlain by west-dipping blind thrust faults.

Fault geometry of the Nodera fault of the Ouchigata fault zone in the southern part of Noto Peninsula, central Japan.

*Keita Takahashi[1], Kenta Kobayashi[1]

1. Department of geology, Faculty of Science, Niigata University

The Ochigata fault zone is a reverse fault type active fault zone showing NE trending located in central Ishikawa Prefecture (The Headquarters For Earthquake Research Promotion, 2005). Although the main fault zone is continuously distributed along the northwest margin of the Houdatsu Hills, in the southwestern region of the Ouchigata fault zone, the fault shows a distribution that branches and runs parallel from the plain to the hills.Among them, the Nodera fault and the Tsuboyama - Yano fault which constitute the hill side have been shown to have different postures and elevation directions of the fault plane, but the factors have not been clarified, and examples of structural geological studies poor. In this study, field survey, sample analysis and fault analysis were conducted with the purpose of elucidating the morphology and fault geometry of Nodera fault and fault of the estimated inside hills.
The geology of this research area is widely distributed in the Jurassic granitic rocks called the Houdatsusan granitic body, and partly covered in the quaternary.
In this study, the outcrop of the fracture zone was found at the side extension of the Nodera fault. In addition, we found a fracture zone running parallel from the hills of the west side of the Nodera fault. These fracture zone outcrops generally show NNE - SSW trend, the outer edge fault gouge shows oblique deviation sense from lateral displacement, while the fault gouge at the center axis shows reverse fault sense including left lateral deflection component. In addition, in this research area, many faults showing lateral sense are distributed from oblique deviation of NNW - SSE trend, and faults of some NNW - SSE and NW - SE trend faults are distributed.
Stress analysis by multiple inverse method (Yamaji, 2000) was carried out using data obtained from these fault planes. As a result, stress 1 indicating NNE-SSW compression and stress 2 indicating WNW-ESE compression were obtained. Stress 1 corresponds to fault gouge data showing oblique deviation sense from lateral displacement of fault of NNE - SSW trend and fault gouge data showing reverse fault sense of NW - SE trend. These are considered to be formed before the stress 2 because they are cut into the fault plane corresponding to the stress 2. The data obtained from the central axis of the fault of NNE - SSW and NNW - SSE trend showing reverse fault sense corresponded to stress 2. This stress is consistent with the current maximum horizontal compressive stress direction by Tsukahara and Ikeda (1991) and CMT (Centroid Moment Tensor) solution of 2007 Noto Peninsula earthquake.
X - ray diffraction analysis was performed on the fault gouge of the fracture zone of the main NNE trend. As a result, the sample at the outer edge of the fracture zone contained a lot of illite and the sample at the center axis contained much smectite. From this, it is considered that the outer edge of the same fracture zone and the central gouge are formed in different environments.
In the previous study (Misaki, 1980), the Nodera fault was regarded as a pure reverse fault sense, but data obtained at the outcrop of the fracture zone may be associated with left lateral deflection component. This is in harmony with the surrounding tectonic relief. In addition, based on the results of stress analysis and X-ray diffraction analysis, it is considered that the faults running along the Nodera fault and the inside of the hills are currently active by reusing previously formed faults.

Keywords: active fault, Ouchigata fault zone, Nodera fault, fault rocks

Comparative study of the active fault zone and the fault zone terminated its activity by the Late Pliocene –examples of the Atera Fault and the Median Tectonic Line in Nara Prefecture

Junichi Tsubaki[1], *Tomoyuki Ohtani[1], Masahiro Kono[1], Keiichi Ueta[2]

1. Department of Civil Engineering, Gifu University, 2. CRIEPI

The activity assessment of the active faults basically needs younger sediments. To understand the fault activity in the area with no younger sediments, it is desired that the new method is developed to study the fault activity from the fault rocks in the basement rocks. For this purpose, both characteristics of the active and inactive fault zones should be clarified. The Atera Fault zone and the Median Tectonic Line (MTL) in Nara Prefecture have studied to understand the above characteristics.
The studied exposure of the Atera Fault is located at Tase, Tsukechi, Nakatsuawa in Gifu Prefecture. In this exposure, the fault is a boundary between the Quaternary sedimentary layers and the Cretaceous granite. The fault is divided into two in the upper part of the exposure. Upper and lower faults are located in the granite and at the boundary of the sediments and granite, respectively. Toda *et al*. (1994) have clarified that the three seismic events are detected from the exposure and that the upper fault have displaced in recent two seismic events.
The studied exposure of the MTL is at Hataya, Ohyodo in Nara Prefecture. In this exposure, the MTL is a boundary between the Quaternary Shobudani Formation and the conglomerate of the Cretaceous Izumi Group. The upper Shobudani Formation with the age ranging from 1.2 Ma to 0.12 Ma have been displaced by the MTL, as shown by Matsumoto (2001). Okada and Togo (2000) reported that the MTL in this area terminated its activity by 0.3 Ma. These suggest that the MTL in this area was active at 1.2 Ma and inactive at 0.3 Ma. The top of the fault exposure had buried in 10 m depth estimated from the distribution of the terrace plain (Samgawa, 1976).
The powder X-ray diffraction (XRD) and the X-ray fluorescence analysis (XRF) were performed using the samples collected from these fault exposures. The XRD results show that smectite appears in the old fault gouge of the Atera Fault, and that plagioclase decreases toward upward in the fault gouge of the MTL. Kaolinite is detected in almost all samples, and smectite appears only the lower part of the fault gouge in the MTL. The XRF results show that MnO extremely increases in the latest slip plane of the Atera Fault, and that the content of MnO in the fault gouge of the MTL is lower than those in the Izumi Group and the Shobudani Formation. Na_2O decreases toward upward in the Izumi Group and the fault gouge of the MTL. The concentration of MnO in the Atera Fault would result from the oxidization of the fault zone near the ground surface. In the MTL, no concentration of MnO is recognized. This is supposed that manganese was concentrated in the past and it was disappeared due to the surface erosion. The distribution of kaolinite and smectite and the decrease Na_2O toward upward suggest that the fault zone of the MTL have suffered surface weathering. The surface erosion of the MTL in the studied site is estimated to be quite low from the distribution of the terrace plain. This indicates that the velocity of the surface weathering have been faster than that of the surface erosion. In the Atera Fault, the granite is uplifted due to the fault displacement, and the fault gouge is presumed to be difficult to suffer the strong weathering. Therefore, the surface weathering of the fault zone is considered to be a possible marker of the recent fault activity.

Keywords: active fault, fault zone, Atera Fault, Median Tectonic Line

Paleoseismic and topographic evidence for latest Pleistocene to Holocene repeated surface-rupturing earthquakes on the Sone Hills fault zone, central Japan

*Tadashi Maruyama[1], Masaru Saito[2]

1. Institute of Earthquake and Volcano Geology, National Institute of Advanced Industrial Science and Technology, 2. Dia Consultants Company Limited

Our paleoseismic trenching and detailed topographic analyses and surveying reveal evidence for multiple large earthquakes accompanied with distinct surface ruptures during the latest Pleistocene to Holocene on the Sone Hills fault zone, central Japan. The ENE-striking Sone Hills fault zone, extending for 32 km, lies southern margin of the Kofu basin which hosts over 200,000 population. Although this fault zone is proximal to well-studied Itoigawa-Shizuoka Tectonic Line active fault zone, its recent rupture history and deformation style are less understood. For properly evaluating the future probability of earthquake occurrence and potential magnitude of ground displacement, paleoseismic information is vital. In order to derive paleoearthquake history we excavated three trenches across the two sub-parallel small scarps on the southern slope of a series of ENE-trending narrow ridges developed at leading edge of the fault zone at Otsuka, Ichikawa-Misato Town, western part of the fault zone. Furthermore, to measure the amount of vertical offset associated with each of possible last two faulting events, we performed detailed topographic analysis of faulted fluvial terraces at Kokubun, Fuefuki City, central part of the fault zone. Trench walls at Otsuka exposed the mid-Pleistocene to Holocene sediments, which are deformed significantly by numerous faults with both the reverse and normal slip components. Such coexisting of reverse and normal slip faults may suggest that the fault zone has a substantial strike-slip component. Based on sedimentary and structural features such as truncation and capping of faulted strata and angular unconformity combined with age controls using radiocarbon dating and tephrochronology, we identified and constrained timing of multiple event horizons, of which two events occurred since the Holocene. Analysis of lidar derived high-resolution DEMs and in-situ topographic surveying using a total station at Kokubun shows that two levels of fluvial terrace surfaces with ca. 10 ka old for its higher one exhibit a ENE-trending linear scarp. The vertical offset of the higher terrace is estimated to be ca. 2.5 m, while that of the lower terrace is less than 1.5 m, suggesting that multiple events occurred during the Holocene period at Kokubun, which is consistent with the results from trenches at Otsuka, and that the vertical offset of the lower terrace shows slip during the last event. This research was carried out as a commissioned research project by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Keywords: Sone Hills fault zone, Paleoseismology, Trenching, Tectonic landform

Tectonic geomorphology and paleoseismology of the northern Neodani fault around Mt. Nogo-Hakusan, central Japan

*Tomoki Tanaka[1], Heitaro Kaneda[1], Tsutomu Inoue

1. Department of Earth Sciences, Chiba University

In the 1891 Nobi earthquake (Mw 7.5), central Japan, three left-lateral active faults, the Nukumi, Neodani, and Umehara faults ruptured simultaneously, resulting in enormous disaster. Although many studies have been conducted after the earthquake along the central and southern Neodani fault, the fault activity and paleoseismic history of the northern section is poorly known principally due to mountainous environment. In order to clarify the activity and earthquake history of the northern part of Neodani fault, we conducted detailed geomorphological interpretation using the airborne LiDAR data and field geological mapping as well as trench excavation at the uppermost Nukumi-Shiratani Valley, southwest of Mt. Nogo-Hakusan, where previous studies reported presence of a fresh fault scarp.

Four fluvial terrace surfaces occur in our study area: NS-I to NS-IV surfaces in descending order. A clear uphill-facing fault scarp cuts across the NS-II surface with a vertical displacement of 3.0 -/+ 0.1 m. In addition, a tributary valley dissecting the surface shows a left-lateral offset of 28 -/+ 5 m, where a fault cutting the NS-II gravels against conglomerate bedrock is exposed on the valley wall.

We excavated a ~5.5-m-long, ~1-m-wide and ~1.5-m-deep trench across the fault scarp. The sediments exposed on the trench walls are topsoil, black peat, lacustrine gray clay, eolian yellowish-brown silt, and gravel layer. The boundary between the yellowish-brown silt and gray clay is very clear, suggesting a drastic change in sedimentary environment. In addition, the gray clay layer bends up towards the fault, which is unconformably overlain by the black peat layer. The organic-rich horizons in the black peat layer are further deformed toward the fault. Based on stratigraphic and structural evidences including those mentioned above, we identified four paleoseismic events after deposition of the NS-II gravels. Our tephra analysis revealed that three of them occurred after the K-Ah tephra fall (~7.3 ka), the latest one possibly correlating to the 1891 Nobi earthquake. Since abandonment of the NS-II surface predates the K-Ah tephra fall but postdates the AT tephra fall (~30 ka), we estimated the left-lateral slip late of this section of the Neodani fault to be at least 2.6 -/+ 1.9mm/yr based on the amount of the stream offset mentioned above.

Our results suggest that the slip rate of the northern Neodani fault is comparable to or even higher than that of the central main section. Of particular interest is that despite presence of such a high slip-rate fault, there are few recognizable tectonic landforms along this section of the Neodani fault except for our study site. This is probably due to high erosion rate in high-relief mountains, suggesting that high slip-rate faults elsewhere may not accompany clear tectonic landforms in high-relief mountainous environment. Tectonic landforms are locally preserved at our study site probably because they are located in the uppermost Nukumi-Shiratani Valley above a clear knickpoint, where severe postglacial erosion has not reached yet.

Keywords: active fault, paleoseismology, LiDAR, Nobi earthquake

Paleoseismology of the Kurozu fault, Nobi active fault system, central Japan: its role in multiple fault rupture

*Sota Takagi[1], Heitaro Kaneda[1], Daisuke Ishimura[2], Daichi Takahashi[3]

1. Department School of Earth Science, Chiba University, 2. Department of Geography, Tokyo Metropolitan University, 3. Graduate School of Science, Chiba University

During the 1891 Nobi earthquake, a well-known example of a multiple-fault rupture, three active left-lateral faults, the Nukumi, Neodani, and Umehara faults, ruptured simultaneously. Previous paleoseismic studies revealed that timing of surface-faulting events on these faults were not always synchronous, suggesting that a multiple-fault rupture as occurred in 1891 is a sort of exception rather than a rule. The Kurozu fault is a ~8-km-long short active left-lateral fault located in between the Nukumi and Neodani faults and is known to have ruptured in 1891 together with these two faults. Although the fault may play a certain role in rupture propagation from the Nukumi fault onto the Neodani fault, very little has been known on its recent fault activity.
At one location, the Kurozu fault cuts across a fluvial terrace surface on the left bank of the Neo-Nishitani River, forming a clear uphill-facing scarp. Our pit excavations into eolian deposits that overlay the terrace surface revealed a horizon of Aira-Tanzawa (AT, ~30 ka) volcanic glass concentration immediately above the terrace gravels. This suggests that the terrace is correlated to a surface downstream that was abandoned 30–40 ka. Our coring and penetration tests on the downthrown side of the fault scarp also suggest that the terrace surface is vertically displaced by ~5.5 m, yielding a vertical slip rate of 0.14–0.18 m/kyr on the Kurozu fault.
We also hand-excavated a trench across the fault scarp, exposing a fault zone that defines a clear boundary between terrace gravels on the upthrown side and peaty and lacustrine dammed-up sediments on the downthrown side. From displacement and deformation of the dammed-up sediments, we were able to identify evidence of only two surface-faulting events after abandonment of the terrace surface at 30–40 ka, including the 1891 Nobi earthquake. This is consistent with a coseismic vertical displacement of ~3 m at the time of the Nobi earthquake, which is about half the ~5.5 m cumulative vertical displacement of the terrace surface.
Our results suggest that a rupture interval of the Kurozu fault is on the order of as long as 10,000 years. This is a good contrast to those of the Nukumi and Neodani faults that are reportedly 2,000–5,000 years. Given that timing of surface-faulting events on these faults were not always synchronous, and also given that the Kurozu fault ruptured in 1891 together with these two faults, we infer that the Kurozu fault plays a critical "relaying" role in rupture propagation across the Nukumi and Neodani faults. Our static coulomb stress modelling also suggests that rupture of the Kurozu fault significantly promotes rupture propagation across these two faults.

Keywords: Nobi earthquake, active fault, trench, slip rate, paleoseismic history

Active faults and their tectonic implication around northern margin of the Sanuki Range, Shikoku region, Japan

*Masayoshi Tajikara[1], Hiroyuki Tsutsumi[2], Hideaki Goto[3], Tokihiko Matsuda[1]

1. Association for the Development of Earthquake Prediction, 2. Department of Geophysics, Graduate School of Science, Kyoto University, 3. Graduate school of letters, Hiroshima University

The Sanuki Range is located in the northeast Shikoku region, and shows elongated shape trending east to west. Southern margin of the Sanuki Range is bounded by the Median Tectonic Line active fault system (MTL), and shows very linear form. Although the Nagao fault is developed along the central part of the northern margin of the Sanuki Range, its distribution is restricted to the central part of the Sanuki Range, and existence of active faults has not been known in the eastern and western extension of the Nagao fault. Based on detailed investigation of aerial photograph and stereoscopic images delivered from 5 m –10 m DEM, we found active faults in the east and west extension of the previous reported active faults. In this presentation, we reported the distribution and characteristics of these active faults, and discuss tectonic implications of these active faults. In the eastern extent of the Nagao fault, left lateral slip fault trending NW-SE and right lateral slip faults trending NE-SW are newly mapped. In one fault, north-side-up displacement is estimated. In the western extent of the Nagao fault, flexure scarps on terrace surfaces trending east-west are newly mapped over several kilometers. In the western side of above mentioned faults, a north-side-up fault known as Kamihogunji fault is distributed. This fault is extended to the east several kilometers by our survey. In the western part of the northern margin of the Sanuki Range, many strike slip faults are newly mapped. Right lateral slips are recognized at NE-SW trending faults, and left lateral slip are recognized at the NW-SE trending faults, respectively. All of these faults are short in length (less than several kilometers), and are distributed intermittently in hilly areas along the northern edge of the Sanuki Range.

Keywords: Sanuki Range, Nagao fault, Median Tectonic Line, active fault

Seismic attenuation profiling for imaging active faults within poorly reflective oceanic crust in Nankai Trough

*Tetsuro Tsuru[1], Jin-Oh Park[2], Tetsuo No[3], Kazuo Nakahigashi[1]

1. Tokyo University of Marine Science and Technology, 2. AORI, University of Tokyo, 3. CEAT, Japan Agency for Marine-Earth Science and Technology

We tested applicability of seismic attenuation profiling (SAP) method as an indicator to understand present fault activity within poorly-reflective incoming oceanic crust in the Nankai Trough. Seismic reflection surveys are usually conducted to investigate fault activities in sedimentary basins, where faults can be specified by offsets of seismic reflections from formation boundaries. However, it is almost impossible to analyze the activities within oceanic crust because seismic reflections are inherently invisible there. Seismic attenuation profiling was, therefore, applied to image faults and investigate their activities within the oceanic crust seaward from the trough axis of Nankai Trough.

The Nankai Trough is the northern margin of the subducting Philippine Sea Plate, where large earthquakes with Mw > 8 have occurred with a recurrence interval of 100 to 200 years. Seismic reflection studies have been carried out in order to figure out geologic structures of the seismogenic plate boundary and splay faults. On the other hand, only a few seismic reflection studies have been applied to investigate intracrustal faults within the incoming oceanic crust, because it is very difficult to observe seismic reflections.

In 2005, high resolution seismic reflection survey was conducted by R/V Kairei of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) on a seismic line NT501H, which was designed along the axis of the Nankai Trough, southwest Japan. Through the surveys, a total of ca 552 km of high-resolution seismic reflection data were collected with two GI-Guns (a total of 12 liter) and a 5100 m streamer cable. Shot interval, receiver interval and CDP interval are 50 m, 25 m and 12.5 m, respectively. The GI-Guns and the streamer cable were towed at 5 m and 8 m depths, respectively. Those towing depths are shallower than ones of conventional Kairei seismic reflection survey (10 and 15m), providing broader frequency bandwidth due to higher ghost-notch frequencies. The broader frequency bandwidth has advantage in estimation of seismic attenuation in frequency domain, such as spectral ratio method.

In order to visualize fault activities in the incoming oceanic crust, we applied SAP that maps seismic attenuation property instead of seismic reflectivity. Spectral ratio method was used to calculate seismic attenuation from multichannel seismic reflection data, because the method is one of the most general methods to estimate Q. In the present study, average Q was calculated only for depths of the oceanic crust as well as the uppermost mantle, in order to avoid influences from sediments and see spatial variation in attenuation property within the igneous oceanic crust. Based on amplitude decay curve analysis, the method is applicable to approximately 10 km depth below the sediments.

Combining the seismic reflection profile and the seismic attenuation profile enables us to understand a whole picture of fault activity. The former clearly shows active and fossil faults in the sedimentary layers. The latter shows active faults within the igneous oceanic crust as high-attenuation anomalies, which extend immediately beneath the active faults that were specified by the seismic reflections. On the other hand, the fossil fault zone was discriminated as low-attenuation zone from the active fault zone, within the oceanic crust.

Keywords: seismic attenuation, fault, oceanic crust

Application of high density CSAMT exploration for active fault investigation by using multi-channel electromagnetic survey system

*susumu sakashita[1], Yusuke Oda[1], Yamashita Yoshihiro[1], Kobayashi Takayuki[1], Douglas Groom[2], He Bin[3], Wang Fei[2], Tomoo Echigo[4], Kyoko Kagohara[5], Shinsuke Okada[6], Shigeru Toda[7], Naoto Inoue[4], Takahiro Miyauchi[8], Toshifumi Imaizumi[9], Hideki Kosaka[10], atsushi miwa[1], yoshikazu matubara[1], Kohei Abe[1], hideki kurosawa[1], Nobuhisa Matsuta[11], Tatsuya Ishiyama[12]

1. OYO corporation, 2. Geometrics, Inc., 3. Laurel geophysical systems, Ltd., 4. GRI, 5. Yamaguchi Univ, 6. IRIDeS, Tohoku Univ., 7. Aichi Univ. of Education, 8. Graduate School of Science Chiba Univ., 9. Graduate School of Science Tohoku Univ., 10. Kankyo-Chishitsu Co. Ltd., 11. Okayama Univ., 12. ERI, Univ of Tokyo

High density CSAMT exploration using the newly developed multi-channel electromagnetic survey system was applied to the study area where active structures may be blind. GeodeEM3D, the survey system can measure six components of electric and magnetic field. Each device allows to establish distributed network by LAN cable of up to 40 EM units. The combination of electric field (E) and magnetic field (H) in one unit can be set variously, such as 4E / 2H, 2E / 3H, 3E / 1H. In addition, it can be used not only for CSAMT using controlled source but also for AMT using natural source. The measurable frequency band is 0.1 Hz to 10 kHz. It is possible to efficiently carry out the high density CSAMT exploration which is capable the small measuring point intervals and dense point distribution. The high-density CSAMT exploration was conducted in the study area where the active structure may be blind (along the Amida River in the vicinity of Yomogita town in the northern part of the Aomoriwan-Seigan fault zone). The length of the measurement line is 4km, the interval of the measurement point is 50m, and the measurement frequency is 0.5Hz to 8192Hz. The geological investigation and the reflection seismic exploration are carried out at this site (Kagohara et al., 2017). The result of resistivity section clearly presents a step with low resistivity zone. Interpretation was made along with the overlapping part with the result of seismic reflection exploration. As a result, we revealed the subsurface structure related to the active fault.

Keywords: Multi-channel electromagnetic survey system, high density CSAMT exploration, seismic reflection exploration, Tsugaru Mountains, subsurface structure, blind thrus

Active tectonics around an ongoing rapid surface deformation area in southern Taiwan by integrating geodesy and field investigation

*Yu-Fang Hsu[1], Ray Chuang[1]

1. Department of geography, National Taiwan University

Mudstone areas in southern Taiwan are located at the frontal fold-thrust belt of the Western Foothills. They are one of the areas with the most active surface movement and rapid topographic evolution in Taiwan. In the past century, there were more than ten disaster earthquakes in southwestern Taiwan. The M 6.6 Meinong earthquake occurred on February 5, 2016 and generated surface rupture along two lineaments near the town of Guanmiao. However, these two structures were neither well documented before nor included in structural models. In addition, the Lungchi area right east of the two lineaments shows both rapid preseismic and coseismic deformation, raising a question if this area is sensitive to stress change or the deformation is just transient. Therefore, this study aims to create a new active structural fault model in this region. We integrate observations from PS-InSAR and GPS to constrain short-term active tectonic patterns and the interseismic deformation rates. Moreover, we map river terraces based on field investigations along the upstream of Erren River to estimate long-term deformation patterns and rates. Thus, we can provide a new model of active tectonic and seismic potential in this area.

Keywords: PS-InSAR, Interseismic deformation, Meinong earthquake

Tectonic features of active faults and seismicity in the Tehran basin, Iran

*Zahra Mohammadi[1], Ahmad Sadeghi[2], Fateme - Saleh[3]

1. Division of Earth and Planetary Sciences, Graduate school of Science, Kyoto University, 2. Head of Tehran Disaster Mitigation and Management Organization (TDMMO), 3. Mitigation and risk reduction deputy of Tehran Disaster Mitigation and Management Organization (TDMMO)

Tehran, capital of Iran, is located at the pediment zone block area of the Alborz Mountains chain, (which form part of the Alps-Himalayan Orogenic Zone) at the abrupt topographic boundary between the mountain range and the northern border of the central Kavir Desert. The urban area of this megacity is located near seismically active faults in the north, (Tchalenko et al., 1974). The presence of diverse faults with evidence of internal post-Pleistocene deformation in this zone confirms its vulnerability to further destructive earthquakes, because the Tehran region has not experienced any major destructive earthquakes at least since 1830, therefore it is necessary to study the active tectonics and evaluating fault seismicity to detect the active faults. The border between the Alborz Mountain and the Tehran’ s piedmont (northern part of Tehran City) is marked by the North Tehran Fault dividing the Eocene rock formation from the alluvial units of different ages (Early Pleistocene to the recent alluvium).
In this study, we focus on the deformation features of active faults developed in the Tehran basin, based on the deformation features of active faults developed in the Tehran basin, based on the interpretations of aerial photographs, perspective view of DEM, Google Earth and satellite imageries, geomorphic indices, seismic data and field investigations. Field investigations guided by the interpreted results of images and analysis of geophysical data reveal that the active faults are mainly developed along the topographical boundary between the mountains and basin, which are characterized by the deformational feature of oblique thrusts with horizontal displacement component. The faults mainly strike E–W to ENE–WSW (?) and dip to north with varied angles between ~25° and 85°. Locally, the faults are characterized by left-lateral strike-slip topographical features, with systematic left lateral offset or deflection of valleys and streams. The faults cut the terrace risers and alluvial fans which are inferred to be formed in the late Quaternary and Holocene, indicating the current activity of these faults. Seismic data also show that the many historical earthquakes and many micro-earthquakes occurred in the study region, consistent with our results. Our results show that the active faults in the Tehran region are the potential source of large earthquakes and may require further more study for accessing the seismic hazard in the densely populated urban regions around the Tehran city, Iran.

Keywords: Tehran, Alborz Mountains chain, Kavir Desert, geomorphic indices, index of relative active tectonics (IRAT)

Tectonic features of active faults and seismicity in the Tehran basin, Iran

Abstract: Tehran, capital of Iran, is located at the pediment zone block area of the Alborz Mountains chain, (which form part of the Alps-Himalayan Orogenic Zone) at the abrupt topographic boundary between the mountain range and the northern border of the central Kavir Desert. The urban area of this megacity is located near seismically active faults in the north, (Tchalenko et al., 1974). The presence of diverse faults with evidence of internal post-Pleistocene deformation in this zone confirms its vulnerability to further destructive earthquakes, because the Tehran region has not experienced any major destructive earthquakes at least since 1830, therefore it is necessary to study the active tectonics and evaluating fault seismicity to detect the active faults. The border between the Alborz Mountain and the Tehran's piedmont (northern part of Tehran City) is marked by the North Tehran Fault dividing the Eocene rock formation from the alluvial units of different ages (Early Pleistocene to the recent alluvium).

In this study, we focus on the deformation features of active faults developed in the Tehran basin, based on the deformation features of active faults developed in the Tehran basin, based on the interpretations of aerial photographs, perspective view of DEM, Google Earth and satellite imageries, geomorphic indices, seismic data and field investigations. Field investigations guided by the interpreted results of images and analysis of geophysical data reveal that the active faults are mainly developed along the topographical boundary between the mountains and basin, which are characterized by the deformational feature of oblique thrusts with horizontal displacement component. The faults mainly strike E–W to ENE–WSW (?) and dip to north with varied angles between ~25° and 85°. Locally, the faults are characterized by left-lateral strike-slip topographical features, with systematic left lateral offset or deflection of valleys and streams. The faults cut the terrace risers and alluvial fans which are inferred to be formed in the late Quaternary and Holocene, indicating the current activity of these faults. Seismic data also show that the many historical earthquakes and many micro-earthquakes occurred in the study region, consistent with our results. Our results show that the active faults in the Tehran region are the potential source of large earthquakes and may require further more study for accessing the seismic hazard in the densely populated urban regions around the Tehran city, Iran.

Keywords: Tehran, Alborz Mountain chain, Kavir Desert, geomorphic indices and index of relative active tectonics (IRAT)

