Faulting history and segmentation of the Tokamachi Fault Zone in Niigata Prefecture, Central Japan

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Tokamachi basin, which located in the southern part of Niigata Prefecture, is bounded by active faults along both of east and west sides of its basin. Those faults are called as Tokamachi Fault Zone, which is divided into two parts, the eastern and the western segments by HERP (2005). In their fault map, the western segment distributes along the western margin of basin from north to south, then after crossing the Shinano river, it continues to the Tsunan and Miyanohara faults with direction of NE-SW to N-E on the another side of the Shinano river. HERP (2010) evaluated the timing of faulting events on both segments of Tokamachi Fault Zone, though there was no data about Tsunan and Miyanohara faults. We will present new data of activities of these faults based on geomorphological and geological surveys as well as discussion on segmentation of Tokamachi Fault Zone deduced from the paleoseismological data of this fault zone and the geological structure of this region.
On Tsunan fault, we excavated all core borings and a pit along two lines across the fault scarplet at Himizo, Tokamachi city. Fault cuts Holocene fluvial terrace with direction of NE-SW and produces east-facing-scarplet with height between 2-5 meters. We excavated boring of depth with 4-5 meters at 4 sites along the southern line and 3 sites along the north line. A pit with 7 meters in length and 2 meters in depth, was excavated on the north line.
On Miyanohara fault, which is located on the late Pleistocene fluvial terrace near the prefecture boundary between Niigata and Nagano, we excavated all core boring at Kameoka, Tsunan town. Borings with depth of 10 meters were excavated at 5 sites across the south-facing fault scarp with 5 m height and an extra-boring with depth of 21 meters on the down-thrown side of the fault scarp.
We also conducted trenching surveys on the eastern segment of Tokamachi Fault Zone at 2 sites, Otajima and Baba. One of results from Otajima will be presented by another presentation in this session (Taniguchi *et al*., 2016). About another result at Baba, we could not find any faults on the trench walls, meaning the scarplet produced not by faulting but by erosion of a blanch stream of the Shinano river.
In our presentation, we will present the history of the fault activities and slip-rates of these faults by using the results of 14 dating and tephra analysis. And, we will discuss the segmentation model of Tokamachi Fault Zone, based on comparison with those data in Tokamachi basin area and difference of geological structure both side of basin.
The contents of this presentation is a part of the result of the Complementary Survey Project of Active Fault by HERP in 2015 FY.

Keywords: active fault, Tohkamachi Fault Zone, faulting history, segmentation of fault, trenching survey, Niigata Prefecture

Dating of marine terraces based on arrayed boring cores in Chikura Lowland, Southern Boso Peninsula, and restriction of history of Kanto earthquakes

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It is well known that along the Sagami Trough, located in the south of Kanto region, central Japan, two great earthquakes occurred as the 1703, M 8.2, “Genroku” Kanto earthquake and the 1923, M7.9 “Taisho” Kanto earthquake. To increase our ability to forecast such megathrust earthquakes, it is important to paleo-seismologically estimate the history of past events from geological evidences along the coast. The recurrence intervals of these earthquakes have been deduced from 14C age of the shell fossils picked from marine terraces considered that were emerged at the time of the past Kanto earthquakes. Based on these measurements, the recurrence intervals of so-called Genroku type, which is the larger one, have been considered to be ~2,000 to ~2,700 years from these evidences (Nakata et al., 1980). However, some recent studies on paleoseismology (Uno et al., 2007; Shishikura, 2014) and geodesy (Sagiya, 2004) have provided new evidences contradict to such construction, leading to the need for reevaluating the history of the past earthquakes there. In this study, we aim to reexamine the emergence history of the marine terraces in the Chikura lowland, located on the eastern side of the southernmost part of Boso Peninsula based on the arrayed drilling core samples newly obtained by an AIST/GSJ project.

We used the drilling cores obtained from four steps of marine terraces which are named Numa I, II, III, IV, (Nakata, 1980), and identified in Chikura lowland along the two observation lines. We inferred and interpreted the sedimentary environment of the strata of each depth and collected shell fossils for dating marine terraces. We could obtain the fossil samples from strata probably deposited in shoreface suggesting nearly the timing of uplift as inferred from the lithofacies and habitat environment of the shells. The radiocarbon dating was conducted by using accelerator mass spectrometry (AMS) deployed in the Atmosphere and Ocean Research Institute, University of Tokyo, which enabled the highly accurate measurement of approximately 30 years of the measurement error. From the result of radiocarbon dating, it is deduced that the highest terrace (Numa I) in Chikura lowland was emerged at ~6,300 cal yBP, the second (Numa II) was after ~3,000 yBP and the third (Numa III) was after ~2,000 yBP. These dates show the later ages than previously well-accepted data: Numa I was ~7,200 cal yBP, Numa II was ~5,000 cal yBP, Numa III was ~3,000 cal yBP. We considered newly examined the amount of the ocean reservoir effect, $\Delta R = 60\pm31$ years.

Compared with the previous results obtained in the other areas in the southernmost part of Boso Peninsula, it is reasonable to consider that the terrace previously regarded as Numa II in Chikura actually corresponds to Numa III terrace of the western coast. Then, it comes to show the existence of some discontinuity of marine terraces between eastern and western coast of the southernmost part of Boso Peninsula. As a result of investigation on the physically constrained fault model, it seemed to be unreasonable to consider the existence of earthquakes, which produced significant gap in the amount of uplift between the eastern and western coasts of the southernmost Boso Peninsula (See the presentation by Komori et al., 2016, this meeting). Thus, the revealed inconsistency in the age of marine terraces may be discussed more in-depth from the viewpoint of the problem in identification of marine terraces or certainty of radiocarbon dating including those for the other areas done in previous studies. We will conduct the similar surveys for the other areas of this region to reexamine the history of the Kanto earthquakes.

Keywords: Kanto earthquake, Marine terrace, paleo-seismology

Did the east-ward migration of the Amur Plate cause the series of inland large earthquakes from central Honshu to eastern Kyushu during late 16 th century ?

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A series of large inland earthquakes including the 1586 Tensho earthquake (M7.8+/-0.1) and the 1596 Keicho earthquake (M7.5+/-0.25) occurred in the central to western part of Japan arc during late 16 th century. The source faults of these earthquakes are active faults in central Honshu Island (Shogawa fault zone, Atera fault zone and Yoro-Kuwana-Yokkaichi fault zone) and the Median Tectonic Line active fault zone in Shikoku Island and eastern Kyushu Island. These source faults locate along the south-eastern marginal area of the Amur Plate demonstrated by Tamaki and Honza (1985) and Taira (2001). The source faults in the central Honshu Island can be projected on the N10W direction line which is normal to the motion of the Amur Plate and strike of the Median Tectonic Line in Shikoku and eastern Kyushu Island with a little gaps and a little overlaps except for the southern-most part (Arima-Takatsuki fault zone). Toda (2011) calculated static Coulomb stress changes by movement of one of the source fault of the Tensho earthquake source faults, and he made clear only little stree change caused on the other source faults. These two facts suggest that the east-ward migration of the Amur Plate is a major factor of series of major inland earthquakes in late 16th century. This hypothesis would support that southeastern margin of the Amur Plate makes broad collisional plate boundary in central Honshu Island (Komatsubara, 2015), and huge earthquake sequence which total seismic moment is compatible with the plate boundary earthquake would occur.

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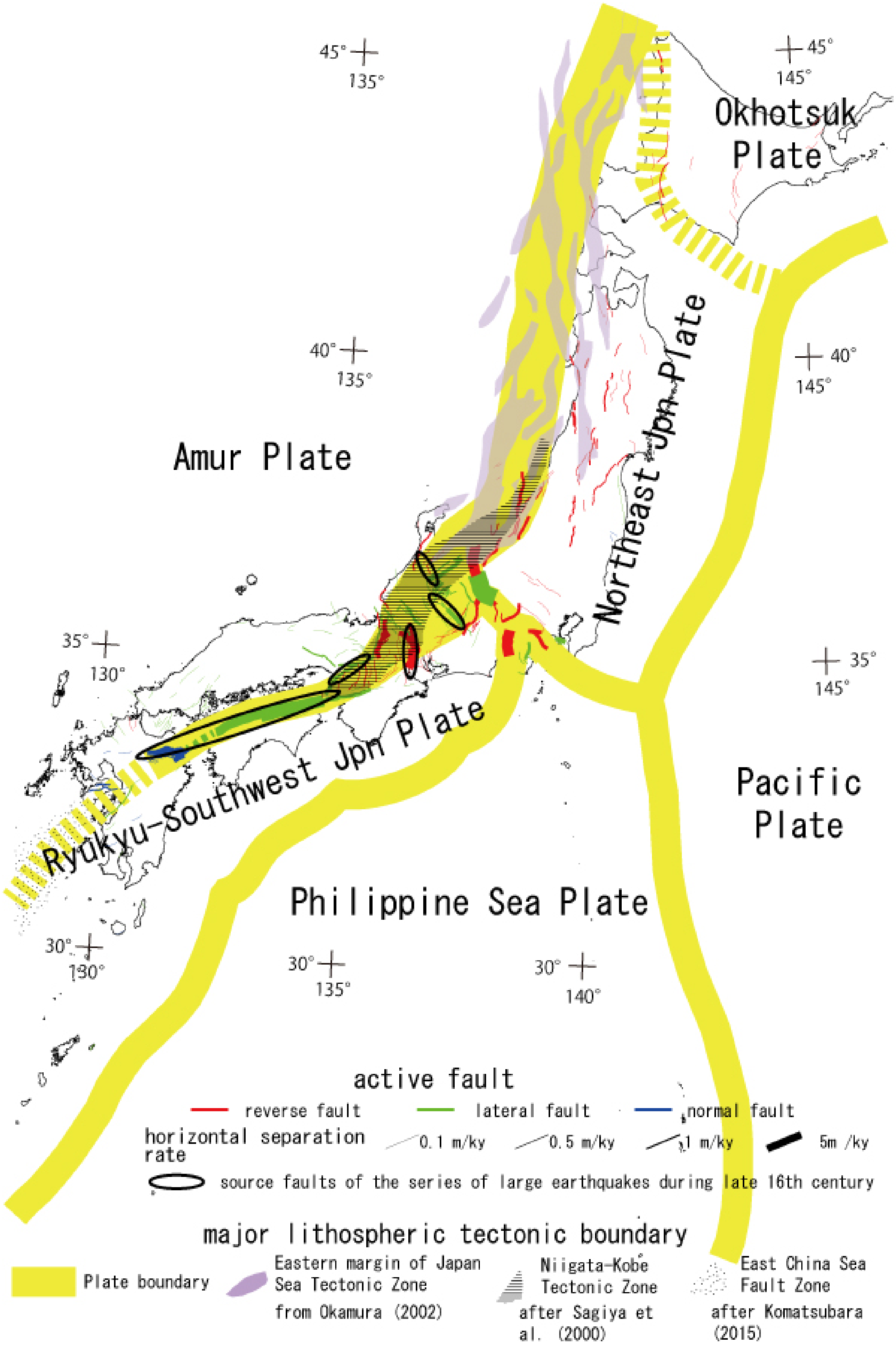
Keywords: historical earthquake, huge inland earthquake, Amur plate, collision boundary, central Honshu


45° 135°
45° 145°
Okhotsuk Plate
40° 135°
40° 145°
Amur Plate
Northeast Jpn Plate
35° 130°
35° 145°
Ryukyu-Southwest Jpn Plate
Pacific Plate
Philippine Sea Plate
30° 130°
30° 135°
30° 140°
active fault
reverse fault
lateral fault
normal fault
horizontal separation rate
0.1 m/ky
0.5 m/ky
1 m/ky
5m /ky
source faults of the series of large earthquakes during late 16th century
major lithospheric tectonic boundary
Plate boundary
Eastern margin of Japan Sea Tectonic Zone
from Okamura (2002)
Niigata-Kobe Tectonic Zone
after Sagiya et al. (2000)
East China Sea Fault Zone
after Komatsubara (2015)

Application of Dating Method by Free Iron Oxides Analysis for loess sediments (Red-Brown soil Layer) of Matsue Area, Japan

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As an alternative to soil dating method by using widespread tephras, it is proposed dating method based on free iron oxides analysis by Nagatsuka (1973).
In the Matsue area, tephras from Sanbe volcanoes (SK, about 105ka) and Daisen volcanoes (DMP, about 130ka) are preserved. In this study, the authors examined the applicability of dating method by free iron oxides analysis for loess sediments (Red-Brown soil layer) below the DMP.
As a result, loess sediments below the DMP is classified red soils by Nagatsuka (1973).
Sasaki(2011) proved that it would take about 125ka for red soils to develop. The age is most consistent with tephra stratigraphy and chronology.
It shows that this method can be a good index of the degree of soil development.

Keywords: Free iron oxides analysis, Crystallinity ratio, Soil age, Loess sediments, Red soil, Matsue area

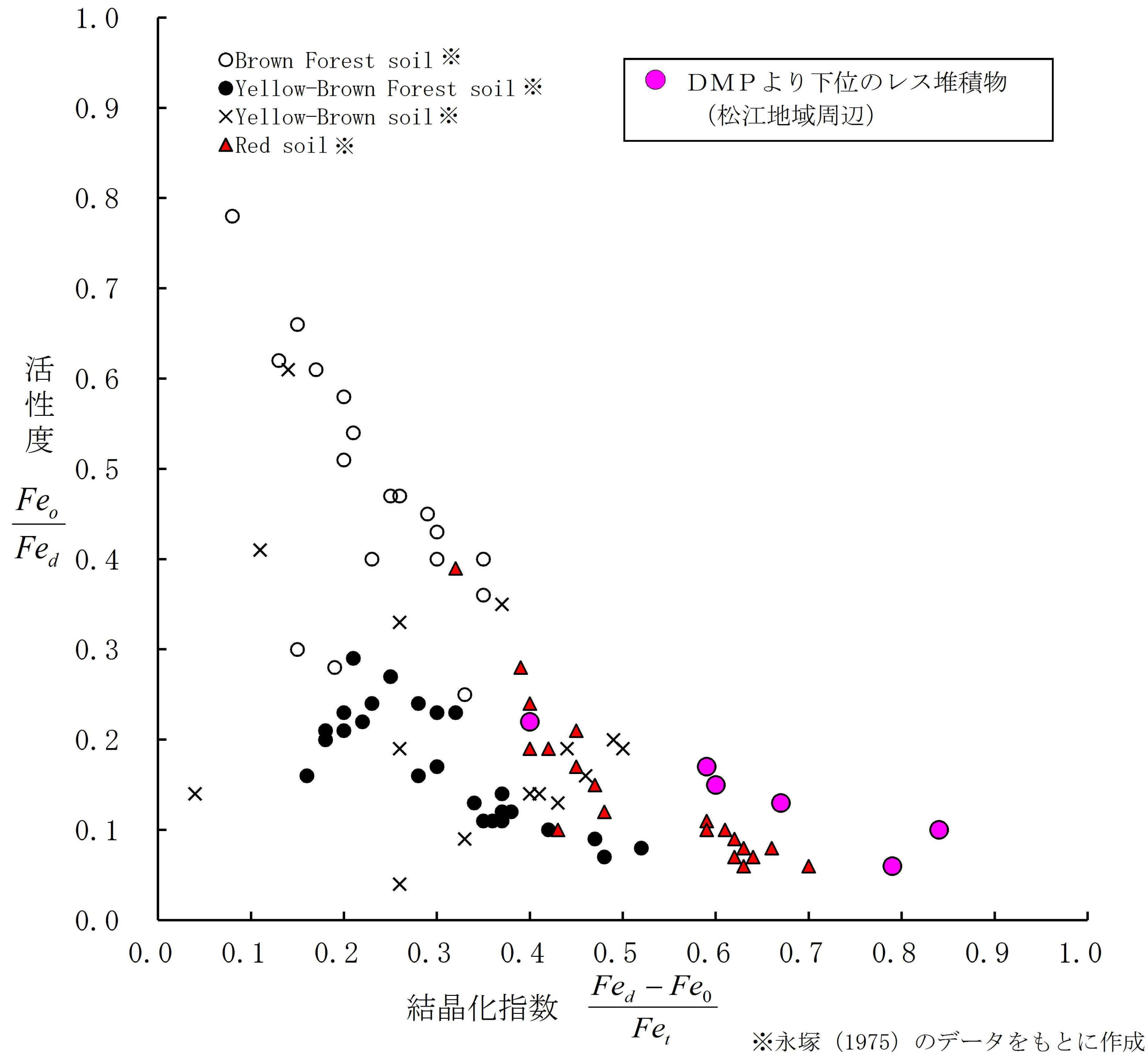

図　DMPより下位のレス堆積物における活性度－結晶化指数の関係

Paleoseimological study of the Midorikawa fault zone in Kyushu Island, Japan

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Midorikawa fault zone is distributed between Yamato town and Misato town, Kumamoto prefecture, Kyushu Island, Japan which has ENE-WSW direction. This fault consists of clear geological boundary at the northern margin of Kyushu Mountains and it is partially overlaps with Usuki-Yatsushiro Tectonic line which divide Inner and Outer zones of the Southwest Japan (Saito et al., 2005, 2010). Therefore, Midorikawa fault is a part of an important tectonic line at the geotechnical subdivision in the Southwest Japan.

The Headquarters For Earthquake Research Promotion released the long term estimation for the Midorikawa fault zone on February 2015, and the fault zone shows normal fault with dextral strike-slip and the dipping angle is about 70-90 degree to the north direction. Average recurrence interval was estimated about 34,000-68,000, if the dextral movement was negligible. However, no trench and boring investigation has ever done for the Midorikawa fault zone and the specific paleoseismological data has not been obtained. Thus the AIST accepted the contracted study in 2015 from the Ministry of Education, Culture, Sports, Science and Technology and did the investigation for the paleoseismic record.

Our field work is done at the Kariya, Yamato town where is located Kamano fault which is the the eastern margin of the Midorikawa fault zone (Chida, 1980), graben structure is developed in this area. Four boring research were done before the trench and all core consist of Aso-4 pyroclastic deposit, loam, humic silt, orange-colored pumice layer, loam and humic silt from bottom to top. An orange-colored pumice layer is overlaying the humic silt, thus it is possibly the Kusasenri-gahama pumice (Kpfa, 31ka) layer (Miyabuchi et al., 2003). The trench was dig across the southern edge of the graben and it size is around 16m×4m×2.5m. Loam, Kpfa, humic silt, loam and black soil was exposed from the bottom to the top. There is a clear fault which displace the Kpfa and dipping to the north direction, This indicated that Kamano fault is activated after the Kpfa. There are another few displacement is recognized therefore few events is suggested at the hanging wall side.

We will discuss the paleoseismic record with the carbon dating data in detail.

Keywords: Midorikawa fault zone, active fault, paleoseismology

Elucidation of activity history on Yatsushiro-sea submarine fault group-Challenge to the Seismic Trenching using high-resolution seismic survey-

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[Background]
In the survey for the offshore active faults, generally seismic exploration is used. However, in seismic explorations, these are emphasis on the grasp widely geological structure with survey lines of several 100 meters or several kilometers interval. So, estimation of faulting with high -precision has not yet at offshore area.
[Purpose]
In this study, we aim to clarify the subsurface deformation of fault using high-resolution seismic survey with 20-50 meters interval survey lines.
Target area is Yatsushiro-sea which is located Midwest of Kyushu. Yatsushiro-sea is the south part of Hinagu Fault Zone. Hinagu Fault Zone is extending from Aso volcano to Yatsushiro-sea. In the Yatsushiro-Sea, some seismic explorations were carried out so far.
[Results of seismic survey]
1) Distribution of faults
A-FA1 fault with NE-SW direction is distributed in central part of survey area. And A-FA1 extends to the NNE direction (based on Kagohara et al., 2011). In west side of A-FA1, we observed some faults which is extends to NE-SW direction and curves clockwise. Three faults extend to NW-SE and oblique to A-FA1 with high angle.
2) Acoustic stratigraphy and activity history
We recognized 7 depositional sequences (A1, A2, A3, B1, B2, C, D layers from the top) based on reflection patterns. Result of piston coring, we estimate formed period of some unconformity,1) reflector R1 (between D and C layers) is Last glacial maximum erosion surface,2) reflector R2 (between C and B2 layers) is Post-glacial erosion surface,3) reflector R5 (between B1 and A3 layers) is about 3,000 yBP. Central part of A area, we identified at least 5 paleoseismic events. And the latest paleoseismic event is occurred between 1,700y BP and 1,000 y BP.

Keywords: Hinagu Fault Zone, Yatsushiro-sea submarine fault group, Strike-slip fault, Seismic Trenching

Tsunami deposits of the 863 (Jogan 5) earthquake in Junicho Lagoon Swamp, along the western Toyama Bay, central Japan

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No large earthquake tsunami has not been recorded in recent years in Toyama Bay. However, earthquake tsunamis have sometimes occurred in the eastern margin of Japan Sea and the most recent historical example attacked the Toyama Bay is the 1-2 m tsunami in Himi City, which was raised by the source fault of the 1833 offshore Yamagata Prefecture earthquake. In order to search for the pre-historical evidences for tsunamis, marine event deposits (tsunami deposits) transported by the earthquake tsunami were deciphered.
Firstly, we analyzed core samples from the southern Toyama Bay coast of the former Houjozu Lagoon and discovered benthic foraminiferal shell in tsunami deposits. From microscopic observations, it became clear that sample No. 5-2 from the Hojozu Lagoon is a tsunami deposit and that the tsunami hit after 2974-2834 calBC and before 1910-1754 calBC. Sedimentological characteristics of sample No. 5-2 indicate that tsunami deposits arond Toyama Bay, might offer an index evidence for determining tsunami deposits. The major features are aggregated sand, allochthonous shells, and benthic characteristic foraminiferal shells derived from greater depth [*Ammonia ketienziensis* (Ishizaki)], and abundant coastal benthic foraminiferal shells (*Ammonia beccarii*).
Along the western Toyama Bay coast, a layer of strange event-deposits containing miscellaneous materials (fossil shells, wood and earthen ware pieces, etc) derived from both land and sea were found in the Junicho Lagoon Swamp in Himi City. The strange assemblage in the deposits was already reported by Matsushima (1981) who pointed out that an earthquake and/or paleocurrent from tsunami could be responsible. In order to identify the factor responsible for these event deposits, the University of Toyama Tsunami Mitigation project carried out drilling surveys at Kubo and Iseomachi in Himi City where core samples (sampleNo.901-1) and (sampleNo.145) respectively were collected. As a result, it was found that the event deposits consist of coarse sand layer which apparently corresponds to the above the Junicho deposits.
This study aimed to make the description and correlation of the core samples, and to reveal the factors and timing of formation of these event deposits. In order to determine the formation age of the event deposits recovered from drilling point of sample No.145, analyses of benthic foraminiferal shells using stereoscopic microscope were conducted as well as radiocarbon dating and an appraisal of pottery pieces.
From the results, the event deposit has been established to be in a marine origin, although no foraminiferal shells of deep-sea origin was detected yet. Based on the dating data, the stratigraphy of the Junicho event deposits was correlated to that of the drill-core sample No.145 and the marine event was found to have been occurred at a time between 1700 BP (calendar year AD315) from 826 BP (AD1190). As for the historical records during this period, the only earthquake tsunami that might bring a great damage to the ancient Toyama was found to correspond to the Jogan 5 (July 10 AD863) Etchu and Echigo earthquake.
As future challenges, it is necessary to find any benthic foraminiferal shells derived from the deep-sea bottom of Toyama Bay to exclude the probability of tidal swell origin for marine event deposits.

Keywords: earthquake tsunami, Toyama Bay, event deposits

Re-examination of scaling relations for crustal earthquakes.

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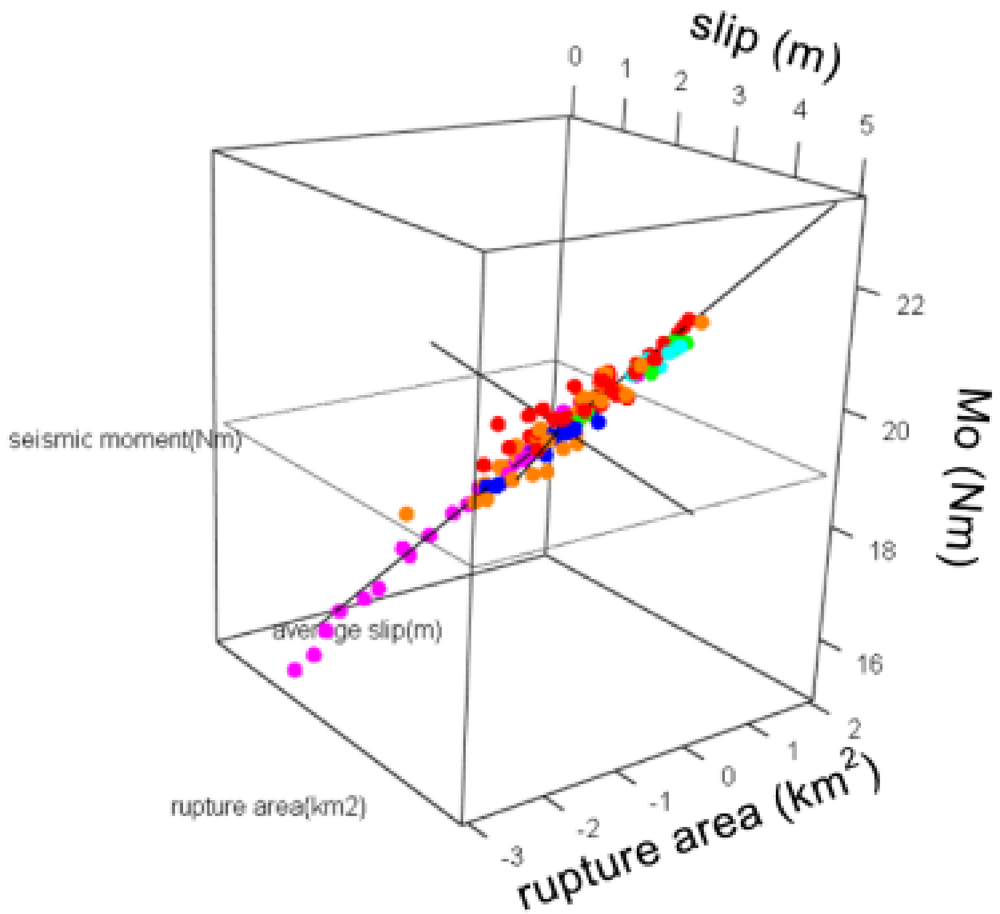
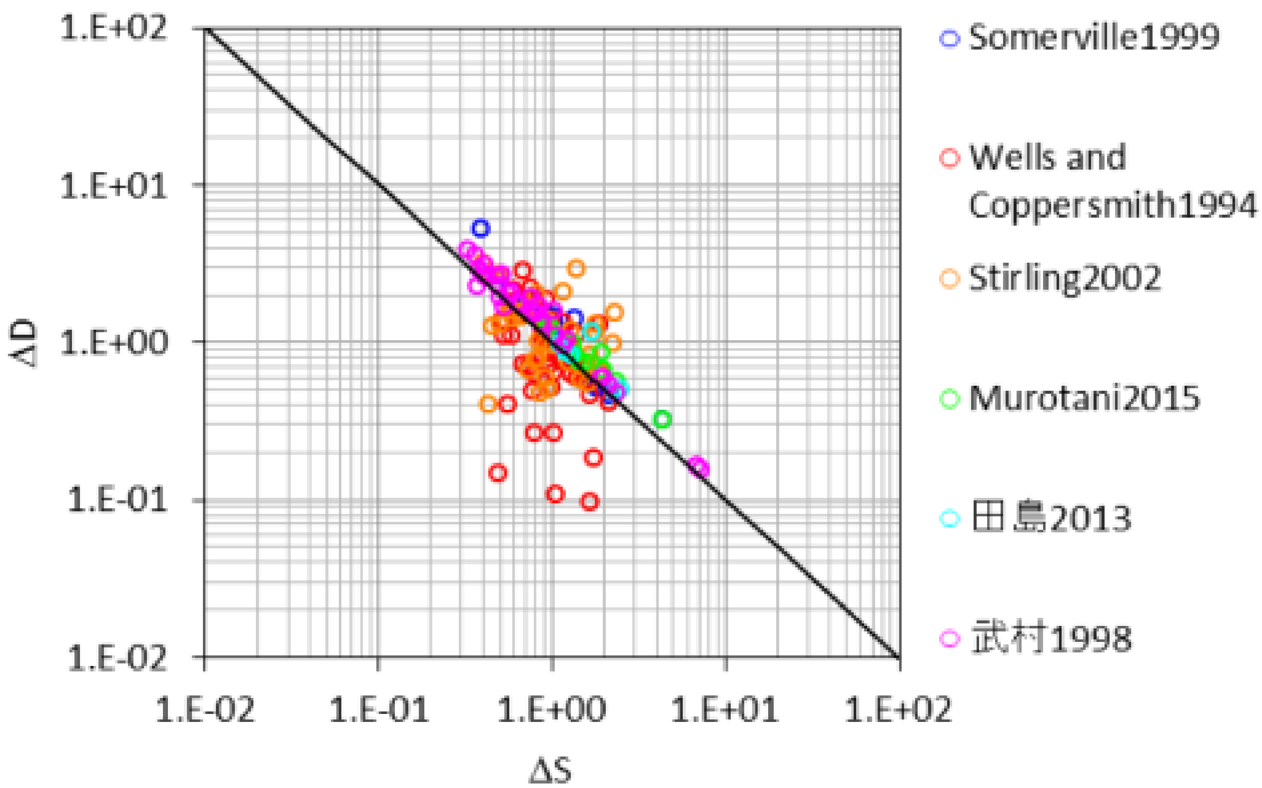
Some of the scaling formula have been already proposed for crustal earthquakes (e.g. Matsuda (1975), Takemura (1998), Irikura and Miyake (2001), Tajima addition (2013) and Murotani et al. (2015)). Matsuda (1975) and Takemura (1998) showed scaling relations between fault length L and magnitude of earthquakes. Also, Irikura and Miyake (2001), Tajima et al. (2013) and Murotani et al. (2015) proposed scaling relations between fault area S and magnitude or seismic moment.
1) Matsuda (1975) : $\log L=0.6M_j-2.9$
2) Takemura (1998) : $\log L=0.75M_w-3.77$ $(6.8\leq M_w)$
3) Irikura and Miyake (2001) : $M_0=(S/4.24\times10^5)^2\times10^{-7}$ $(6.5\leq M_W<7.4)$
4) Tajima et al. (2013) : $M_0=0.877\times S\times10^{11}$ $(7.5\leq M_w)$
5) Murotani et al. (2015) : $M_0=1.0\times S\times10^{11}$ $(7.4\leq M_w)$
These scaling formulas indicate relation between one variable parameter (i.e. fault length L or fault area S) and the seismic moment or magnitude. When we calculate seismic moment with these scaling formulas and slip amount using the formulas, Mo=μDS and S=LW, the resulting slip amounts vary from formula to formula. When we assume a fault with L=50km and W=20km, we obtain Mw=7.10 and average slip D=1.64 by Irikura and Miyake (2001) and Mw=7.29 and average slip D=3.21 by Takemura (1998). Such differnces would significantly affect the results of seismic hazard assessments.
In this study we proposed a scaling relation of seismic moment with two variables parameters, fault area S and average slip D. We used the same earthquake data used in Irikura and Miyake (2001) and Takemura (1998). We obtained regression line with principal component analysis. The relation between the residual of slip ΔD and the residual of area ΔS could be expressed by $\log\Delta D = -\log\Delta S$ $(\Delta D * \Delta S = 1)$, which indicates that fault area S and the average slip D are not independent parameters on earthquake data used in this study.

Keywords: scaling relation, crustal earthquake, earthquake source model, earthquake hazard assessment


slip (m)
0
1
2
3
4
5
22
20
18
16
Mo (Nm)
seismic moment(Nm)
average slip(m)
rupture area(km2)
-3
-2
-1
0
1
2
rupture area (km²)


1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
ΔD
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
ΔS
Somerville1999
Wells and Coppersmith1994
Stirling2002
Murotani2015
田島2013
武村1998

A Bayesian prediction for active faults using spatial similarity of variation of recurence intervals

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We propose a new Bayesian method of probability prediction for recurrent earthquakes of inland active faults in Japan. Renewal processes with the Brownian Passage Time (BPT) distribution are applied for over a half of active faults in Japan by the Headquarters for Earthquake Research Promotion (HERP) of Japan. Long-term forecast with the BPT distribution needs two parameters; the mean and coefficient of variation (COV) for recurrence intervals. The HERP applies a common COV parameter for all of these faults because most of them have very few specified paleoseismic events, which is not enough to estimate reliable COV values for respective faults. However, different COV estimates are proposed for the same paleoseismic catalog by some related works. It can make critical difference in forecast to apply different COV estimates and so COV should be carefully selected for individual faults.
Recurrence intervals on a fault are, on the average, determined by the long-term slip rate caused by the tectonic motion but fluctuated by nearby seismicities which influence surrounding stress field. The COVs of recurrence intervals depend on such stress perturbation and so have spatial trends due to the heterogeneity of tectonic motion and seismicity. Thus we introduce a spatial structure on its COV parameter by Bayesian modeling with a Gaussian process prior. The COVs on active faults are correlated and take similar values for closely located faults. It is found that the spatial trends in the estimated COV values coincide with the density of active faults in Japan. We also show Bayesian forecasts by the proposed model using Markov chain Monte Carlo method. Our forecasts are different from HERP’s forecast especially on the active faults where HERP's forecasts are very high or low.

Keywords: earthquake recurrence interval, BPT distribution, Coefficient of variation

On the differences of source areas between 1703 Genroku earthquake and 1923 Taisho Kanto earthquake from the detailed examination of seismic intensities

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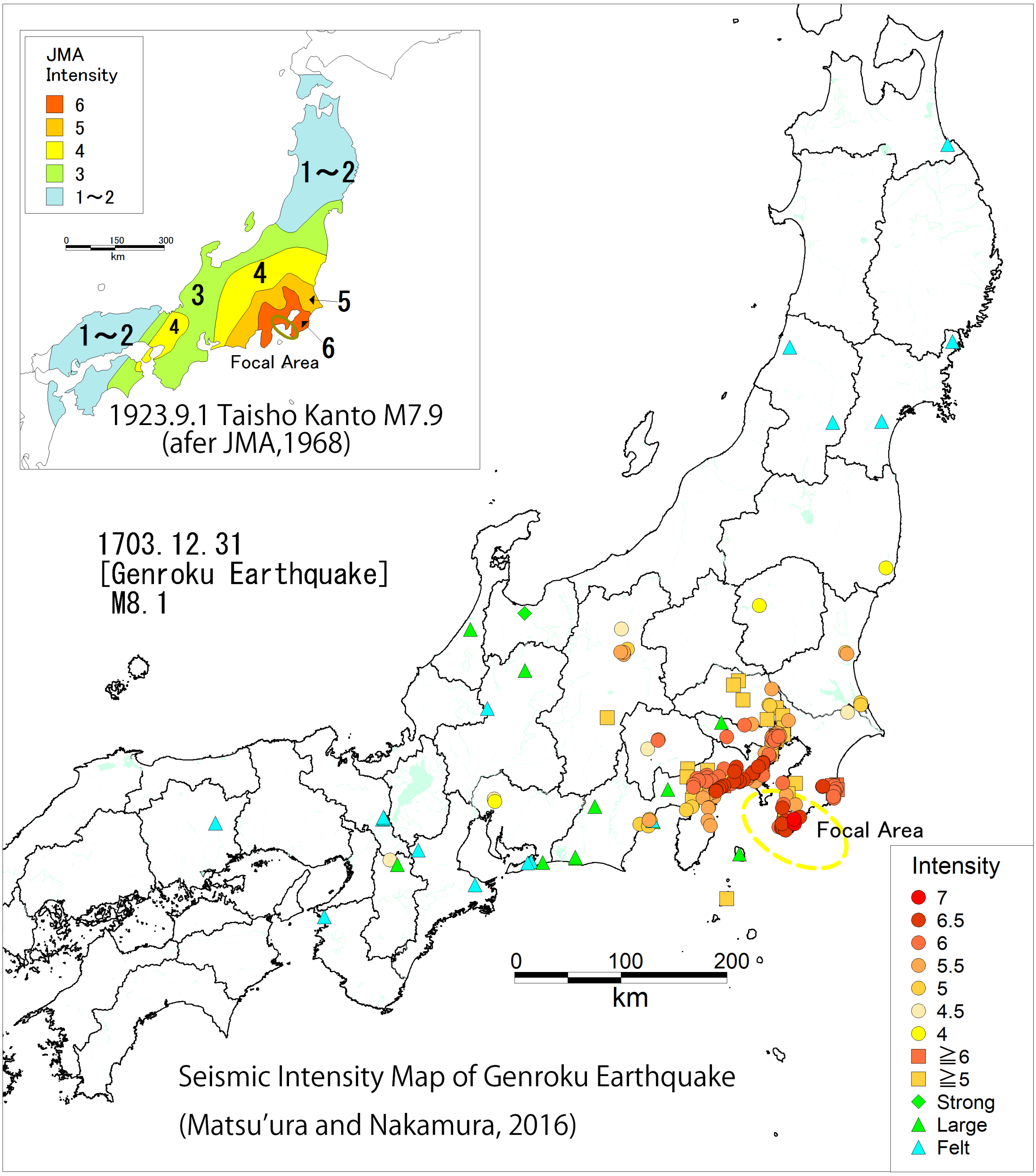
We have examined the whole known historical documents on the Genroku earthquake, other than those related to small houses of bannermen in Edo city. The M8.1 Genroku earthquake occurred at the midnight on December 31, 1703 on the plate boundary along the Sagami Trough. It has been widely believed that the Taisho Kanto earthquake at noon on September 1, 1923 of M7.9, occurred in the western part of the source area of the Genroku earthquake. However, we found that the westernmost part of the 1923 Taisho Kanto focal area, where the Izu peninsula is colliding to the Honshu Island, did not move at the time of Genroku. The seismic intensities of the Genroku earthquake are evidently smaller than those of the Taisho earthquake in the western Japan (Fig. 1). This feature is also apparent even in the existing intensity maps of the both events.
At the time of 1923 event, in Osaka branch of the Bank of Japan, piled up money boxes fell down to the floor. The intensity at the Osaka Meteorological Observatory was 4 at the time of Taisho. However, we have not yet found a historical material, which shows that the Genroku event was felt in Osaka. The 1923 event was followed by many M7-class aftershocks, including the large intra-plate earthquake in 1924 at Tanzawa. After the Genroku event, historical materials only recorded a conflagration in Edo city a few days later, but no strong aftershocks were noted.
The source area of the Taisho Kanto earthquake consists of the plate-boundary type part, which is the western half area of the Genroku earthquake, and the intra-plate type in the westernmost part in Kanagawa Prefecture, which generated strong short-period waves. Taisho event was felt strong in the western Japan. In the Genroku earthquake, the area off the southeastern part of Boso peninsula moved and caused the devastating tsunami disaster along the Sotobo area in Chiba Prefecture. Not only the tsunamis but also the strong motions of both earthquakes are very different from each other. These are not the similar events, nor the characteristic earthquakes. We should mind these differences to plan the disaster mitigation for the next large earthquake in the southern Kanto district.

Keywords: Genroku earthquake, Taisho Kanto earthquake, Sagami trough, Collision of the Izu Peninsula, detailed analysis of historical materials



Seismic Intensity Map of Genroku Earthquake
(Matsu'ura and Nakamura, 2016)

A description of a tsunami in the essay "Kyu-ai Zuihitsu" written by To-u Momoi (? - 1792)

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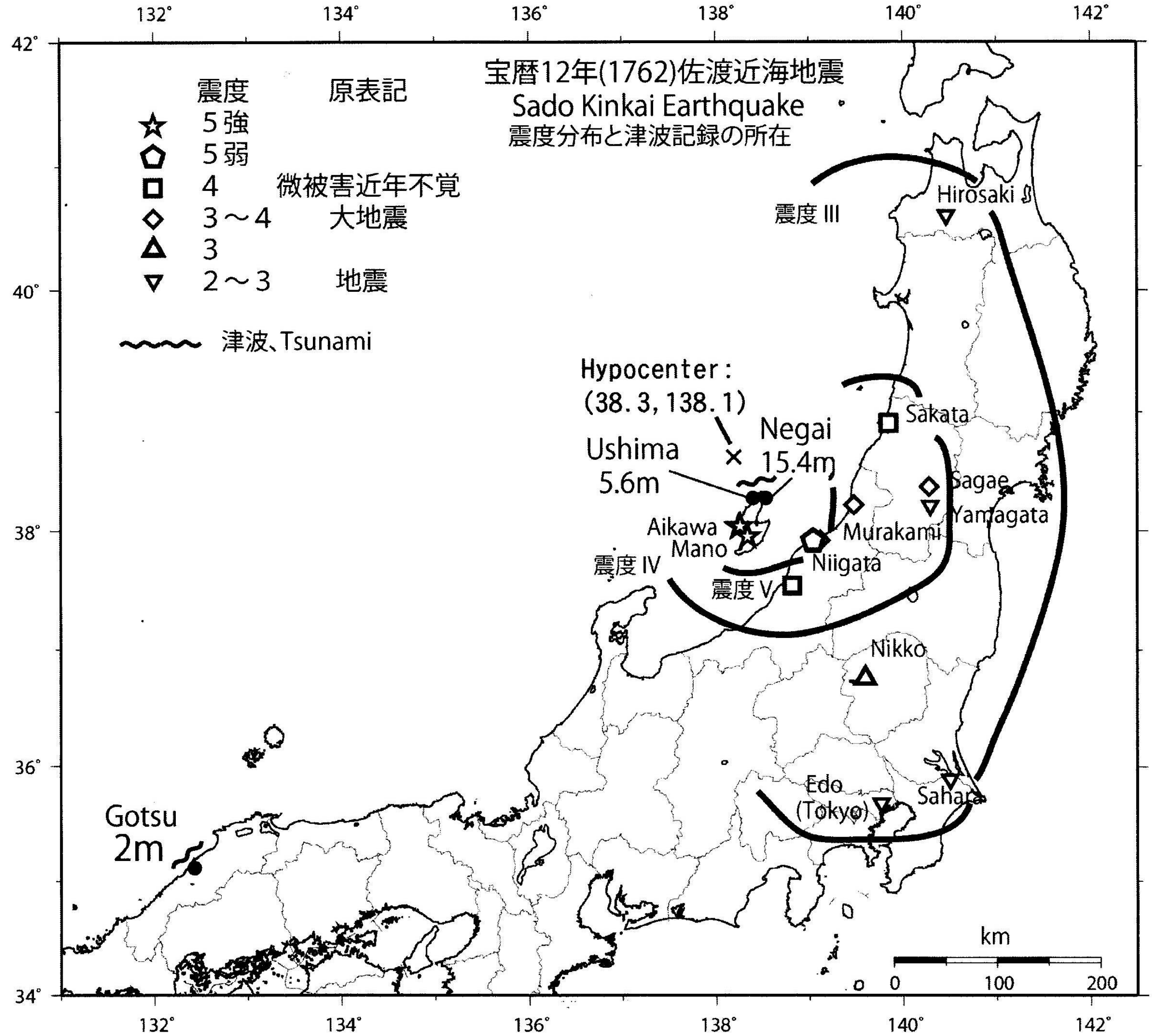
In the end of 18th century, To-u Momoi, who was a son of a rich merchant in Kyoto wrote an essay called "Kyuu-ai zuihitsu". He sent a life of long travels. He began travel in 1758 and finished travels by the end of 1788. He visited almost all part of the Japanese countries, and recorded many episodes experienced in his travel in his essay. But unfortunately, he seldom wrote year of each episode. He mentioned in a section on a tsunami which hit the Japan Sea coast of the mouth of Gonogawa river, Shimane prefecture, Western part of Honshu Island. Unfortunately he did not write the year of the Tsunami. He saw this tsunami from afternoon to the night, and he wrote "it was September and full moon night". We check the tsunami catalog written by Watanabe(1998), and found out that the Sado Kinkai earthquake of October 31, 1762 (September 15, the 12th year of the Horeki Era in Japanese calender).
Acknowledgement: The present study was achieved as a part of the commissioned research on disaster prevention for nuclear facilities named “Study on the historical tsunamis in Japan Sea (2015)” proposed by the Nuclear Regulation Authority, Japan.

Keywords: a tsunami in Japan Sea, a historical tsunami, the 1762 Sado-Kinkai earthquake


宝暦12年(1762)佐渡近海地震
Sado Kinkai Earthquake
震度分布と津波記録の所在
震度
原表記
5強
5弱
4
微被害近年不覚
3～4
大地震
3
2～3
地震
津波、Tsunami
Hypocenter:
(38.3, 138.1)
Negai
15.4m
Ushima
5.6m
Aikawa
Mano
震度 IV
震度 V
震度 III
Niigata
Murakami
Sakata
Sagae
Yamagata
Hirosaki
Nikko
Edo
(Tokyo)
Sahara
Gotsu
2m
km
0
100
200
132°
134°
136°
138°
140°
142°
42°
40°
38°
36°
34°

Examination of the damage description in Kyushu by the large earthquake on June 30th, 1498 on a war chronicle

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On June 30th, 1498, ground shaking was widely recorded in western Japan. Court nobles in Kyoto (the then capital city of Japan) described on diaries strong shaking there in *Saru-no-koku* (3:00-5:00 p.m.) although they did not mention any damage by this earthquake. According to the historical books and chronicles compiled in Edo Period, felt area of this earthquake extends from Osumi region (Kagoshima Pref. at present) in Kyushu Island to Koshu region in Honshu (Yamanashi Pref. at present). Large earthquake in *Mi-no-koku* (10:00-12:00 a.m.) on the same day and serious damage in Kyushu are described on the war chronicle *Kyushu-gunki* which was written in the early 1600s. Although this war chronicle is one of the popular literatures which was written more than 100 years after the 1498 event, the damage descriptions have been accepted by many seismologists without evaluating the reliability, and considered to be important information on the location of this earthquake.

Usami (1987) regarded the earthquake in *Mi-no-koku* as an M~7 event in the Hyuga-Nada Sea on the east side of Kyushu Island along Nankai Trough, while he commented that credibility of *Kyushu-gunki* is low. Tsuji and Ueda (1997) and Tsuji (1999) interpreted a part of the damage descriptions in Kyushu as a tsunami and claimed that the 1498 event was an unknown great Nankai earthquake based on the tsunami around Kyushu and extensive felt area in western Japan. Ishibashi (1998, 2002, 2014), however, pointed out that the 1498 event could not be a great Nankai earthquake because the damage descriptions in Kyushu were doubtful and the interpretation by Tsuji and Ueda (1997) and Tsuji (1999) was unreasonable. Incidentally, Ishibashi (2002, 2014) suggested that the 1498 event was possibly an M~7 intra-slab earthquake beneath Kyushu Island like the 1909 earthquake of M7.6. As mentioned above, the location of the 1498 earthquake has been controversial and it is important to reveal whether serious damage in Kyushu was real or not.

In this study, in order to assess whether the descriptions were credible or not, we carefully examined the damage descriptions in Kyushu on the *Kyushu-gunki*. As a result, they are very suspicious because of following reasons: (1) Damage descriptions in Kyushu were generic without location information. (2) Some major earthquakes in the 1200s and 1400s are listed following the damage description, which clearly indicates that the writers had knowledge of the past major earthquakes. Thus, the descriptions of the 1498 earthquake could also have been taken from historical documents and not original. (3) Origin time (*Mi-no-koku*) of the 1498 event is close to that of the great Tokai earthquake on Sep. 11th, 1498. Therefore, the writers possibly confuse the damage of these two earthquakes. (4) Serious famine in Kyushu in 1503 and pains of people by many disasters are also written in the chapter of the earthquake damage, making this chapter a stage setting for later stories. Therefore, the earthquake damage could be a fictitious story. (5) Since *Kyushu-gunki* was completed in 1607, writers should have experienced the 1596 large destructive earthquake in Kyushu when writing the war chronicle. Thus, this experience might have influenced the description of earthquake damage.

Acknowledgement: This study was supported by the MEXT’s “New disaster mitigation research project on Mega thrust earthquakes around Nankai/Ryukyu subduction zones”.

Keywords: June 30th, 1498 earthquake, war chronicle "kyushu-gunki", serious damage in Kyushu, Hyuga-Nada earthquake, Meio-Tokai earthquake

Paleoseismic study on the Kamishiro Fault, the northern segment of the Itaigawa-Shizuoka Tectonic Line, Japan

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The Mj 6.8 (M_w 6.2) Nagano (Japan) earthquake of 22 November 2014 produced a 9.3-km-long surface rupture zone with a thrust-dominated displacement of up to 1.5 m, that duplicated the preexisting Kamishiro Fault along the Itoigawa-Shizuoka Tectonic Line (ISTL), the plate-boundary between the Eurasian and North American plates, in the northern Nagano Prefecture, central Japan. To better understand the nature of the seismogenic fault zone, we carried out paleoseismic study on the Kamishiro Fault. Field investigations and trench excavations reveal that seven morphogenic earthquakes (E1~E7) prior to the 2014 M_w 6.2 Nagano earthquake have occurred on the Kamishiro Fault during the past ~6000 years, in which the timings of three recent events (E1~E3) corresponding to historical-recorded earthquakes occurred in the past ~1200 years are well constrained, suggesting an average recurrence interval of ~300-500 years on the seismogenic fault of the 2014 Kamishiro earthquake. The most recent event (E1) prior to the 2014 earthquake occurred within the past 200 yr, and corresponds to the 1918 M 6.5. The penultimate faulting event (E2) occurred in the period between AD1800 and AD 1400 and is probably associated with the 1791 M 6.8 earthquake. The antepenultimate faulting event (E3) is inferred to have occurred in the period between AD ~700 and AD ~1000, corresponding to the AD 841 M 6.5 earthquake. The oldest faulting event (E7) is identified to be occurred in the period during ~5600-6000 yr BP in this study area. The vertical slip rate during the early Holocene is estimated to be 1.2-3.3 mm/yr with an average of 2.2 mm/yr. When compared with the active intraplate faults of Honshu Island, Japan, the relatively high slip rates and short recurrence intervals for morphogenic earthquakes within the Kamishiro Fault developed along the ISTL indicate that the present activity of this fault is closely related to seismic faulting along the plate boundary between the Eurasian and North American plates.
Keywords: 2014 M_w 6.2 Nagano earthquake, paleoseismicity, Kamishiro Fault, recurrence interval, morphogenic earthquake, plate boundary

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Keywords: Kamishiro Fault, paleoseismicity, 2014 Mw 6.2 Nagano earthquake, Itoigawa-Shizuoka Tectonic Line active fault system

Seismic cycle of the Kamishiro fault (northern part of the Itoigawa-Shizuoka Tectonic Line active fault system) revealed by tectonic geomorphology at Warabidaira, Hakuba Village, central Japan

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An Mj=6.7 (Mw=6.2) earthquake occurred the northern part of the Itoigawa-Shizuoka Tectonic line active fault system. The surface rupture appeared in association with the earthquake along the previously mapped Kamishiro fault. The maximum vertical displacement of the surface rupture is about 1 m.Long-term Kamishiro fault slip rate estimated of 3-4 mm/yr by drilling survey and tectonic geomorphology. It has believed that recurrence interval of the Kamishiro fault estimates of 1,250 to 1,500 years for the large quakes by trench survey. In this case, average vertical displacement per event estimates of 3 to 4 m.

The magnitude of the 2014 event is smaller than predicted magnitude along the Kamishiro fault. Our aim is to clarify the crustal deformation system in Kamishiro area and therefore investigated it to clarify paleoseismology and the tectonic geomorphology on the surface rupture at Warabidaira in Hakuba village.

We defied five Holocene terraces as Lc2 terrace, Lc1 terrace, Lb2 terrace, Lb1 terrace, La terrace in order of young on the landform classification. The amounts of vertical offset of the Lc2, Lc1, Lb2, Lb1, and La terrace surface are 0.3-0.4m, 0.5m, 1.1m, 1.6m, and 1.5m respectively. The amounts of left-lateral offset of Lc1/Lc2 terrace, Lb2/Lc1 terrace,Lb1/Lb2 terrace,and La/Lb1 terrace are about 1.0m,1.0m 5.0m,and 7.5m, respectively. The Lc2, Lc1, Lb2, Lb1 and La terrace emerged at modern, modern, 1695-1535 Cal.BP, 1530-1355 Cal.BP and 2055-1900 Cal.BP, respectively. The vertical and left lateral average slip rate is calculated to be 0.8mm/yr, and 3.5mm/yr, respectively. The average recurrence interval is 586-880 year.

Keywords: 2014 Kamishiro fault earthquake, surface rupture, trench excavation, left-lateral offset

Vertical slip rate estimated from young lacustrine sediment core samples across the Kamishiro fault, Itoigawa-Shizuoka Tectonic Line, central Japan

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We conducted drilling survey to re-examine a rate of the vertical deformation on the Kamishiro fault, northern part of the Itoigawa-Shizuoka tectonic line active fault system, central Japan. Exacted two cores, obtained on the hanging wall of the Kamishiro fault, consist of paleo-lacustrine sediments (alternation of sand-mud and sand-gravel layers). In the KMS-1 core, closer to the fault trace, extracted strata shallower than a depth of 3.2 m from the surface are horizontally laminated. The core extracted from depths from 3.20 m to 16.20 m exposes inclined strata with apparent dips of 20° to 30°, whereas upstanding strata were recovered from the core depth of 16.20 m to 28.60 m. We encountered horizontaly laminated sand and mud layers again deeper than the sharp boundary at a depth of 28.65 m, In the KMS-2 core, farther from the fault trace, sediments shallower than a depth of 4.20 m are horizontally laminated. At depths from 4.20 m to 38.30 m, inclined strata with dips of 20 to 30 degree was extracted, whereas upstanding strata were recovered with shear planes at depths of 38.30 to 42.17 m. Across the sharp boundary at the core depth of 42.17 m, sand and mud layers return to be horizontally laminated.
We interpret that the sudden lithofacies change from overlying inclined strata to underlying horizontally-laminated strata, commonly shown in the both cores, is penetrating the Kamishiro fault. This interpretation is supported by ^{14}C ages of the two cores. Thus, ^{14}C age is younger (ca. 16,000 yr BP in the KMS-1 core, ca. 24,000 yr BP in the KMS-2 core) just below the horizon shown by the sharp boundary than that above the boundary (ca. 30,000 yr BP in the KMS-1 core, older than 50,000 yr BP in the KMS-2 core). On the basis of altitude of facies boundaries and over fifty radiocarbon ages, cumulative vertical displacements are 12–14 m at 9,000 yr BP, 16–17 m at 11,000 yr BP, ≥41 m at 21,000–24,000 yr BP, respectively. These vertical separations and ages indicate that average rates of vertical displacement in the study area are 1.2–1.4 mm/yr during the past 10 ka, and higher than 1.6 mm/yr during the past 25 to 30 ka, respectively. It implies that a coseismic vertical slip of 0.3–0.5 m at the 2014 earthquake released a strain accumulated during the past 210 to 420 years.

Keywords: Itoigawa-Shizuoka Tectonic Line, Kamishiro fault, vertical slip rate, sediment core, radiocarbon dating

Trench excavation survey across the 2014 rupture zone along Kamishiro fault, Itoigawa-Shizuoka Tectonic Line

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The Mw=6.2 Nagano-ken-hokubu earthquake, central Japan, on November 22, 2014 was accompanied by an ~9-km-long NS-trending surface rupture zone along the pre-existing scarp of the Kamishiro fault, a part of the Itoigawa-Shizuoka Tectonic Line active fault system. This earthquake was the first surface-breaking earthquake to have occurred on one of the 110 major inland active faults prioritized for evaluation by the Headquarters for Earthquake Research Promotion that was launched in 1995 after the 1995 Kobe earthquake. To furnish more paleoseismic data to retrospectively evaluate the seismic hazard and to validate pervasive characteristic earthquake model, we excavated paleoseismic trenches across the 2014 rupture zone at two sites, Oide (northern site) and Iida (southern site). Trench walls at both sites exposed evidence for the penultimate surface-rupturing event that had occurred sometime between ~400 cal. B.P. and present. Together with the documented local damages similar to the ones in 2014, we interpret that the 1714 Otari earthquake of M 6 1/4 would have been the penultimate surface-breaking earthquake along the Kamishiro fault. At Oide, we found three or four paleoseismic events during the past 15 ka whose movements accumulated four-to-six-meter high hill-facing fault scarp. The penultimate event, possibly at the Otari earthquake, could have formed larger coseismic vertical separation comparing to < 1m ground tilt at the 2014 earthquake. At Iida, despite a paucity of sediments and unique deformation as a transverse fault, we found five paleoseismic events during the past 53 ka, which is roughly consistent with the result reported by Okumura et al. (1998), except the penultimate event occurred sometime after about 1700 A.D. that is well constrained from an earthenware fragment yielded from a younger unit.
Acknowledgements: This study was performed as a part of “Additional surveys of the comprehensive study of the Itoigawa-Shizuoka Tectonic Line active fault system, Ministry of Education, Culture, Sports, Science and Technology (MEXT)”.

Keywords: Nagano-ken-hokubu earthquake, active fault, paleo-earthquake, surface rupture

Surface rupture and coseismic deformation associated with the 2014 Nagano-ken-hokubu earthquake revealed from differential LiDAR analysis

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The Nagano-ken-hokubu earthquake occurred on November 22, 2014, along the Kamishiro fault, one of the segments of the Itoigawa-Shizuoka Tectonic Line active fault system. A 9-km-long surface rupture associated with the earthquake indicates a N-NW trending, east dipping fault extended to the hyponcentral depth. We mapped the surface rupture and measured the amounts of vertical and horizontal displacements (Okada et al., 2015; Ishimura et al., 2015). However, due to the limited time allowance until winter snowfall starting from December, we could not homogeneously observe ground deformation along the Kamishiro fault. We thus employ differential LiDAR analysis to reveal precise location of surface rupture and coseismic displacement.

The data sets we used for the analyses are 1 m mesh DTM (Digital Terrain Model) data measured in 2009 (pre-event), 2014 (5 days later from the event), and 2015 (about 1 year later from the event). We applied the particle image velocimetry method to obtain 3-D vectors of coseismic deformation (Mukoyama, 2011). The precision of this method is ~0.1 m.

The result shows a clear contrast of vertical displacements and horizontal vector directions between hanging wall and foot wall sides. The locations of these contrasts are corresponding with our field observations (Okada et al., 2015; Ishimura et al., 2015) and let us know missed surface ruptures. From these results, we confirmed the surface ruptures composing of two or three bow-shaped traces. Vertical displacements at some points are larger than the field measurements, indicating underestimates at the field due to wide warping zone. Horizontal displacement was detected at the extending part of the surface rupture, corresponding with InSAR results.

Acknowledgements

This study was carried out as a part of “Additional surveys of the comprehensive study of the Itoigawa-Shizuoka Tectonic Line active fault system, Ministry of Education, Culture, Sports, Science and Technology (MEXT)”.

Keywords: the 22 November 2014 Nagano-ken-hokubu earthquake, Itoigawa-Shizuoka Tectonic Line, Kamishiro fault, surface rupture, LiDAR

Fault displacement distribution of the 2014 Nagano-ken Hokubu earthquake based on a differential analysis of multi LiDAR-DEM data

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The author shows 3-D fault displacement distribution of the 2014 Nagano-ken Hokubu earthquake using LiDAR-DEM data acquired before and after the earthquake.

Keywords: Nagano-ken Hokubu earthquake, Kamishiro fault, LiDAR-DEM, fault displacement

Interpretation of SAR interferograms on the ground deformation associated with the Northern Nagano Prefecture earthquake in 2014

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Detailed ground deformation associated with the Northern Nagano Prefecture earthquake in 2014 was well recorded in the interferograms of ALOS-2 "Daichi-2" SAR. We focused on the local interferometric patterns considered to be the reflection of local characteristics of surface displacement, and interpreted them to identify the subsurface structure and motion of rupture of the earthquake fault, with references to the results of ground-penetrating radar profiling and trench excavation survey.

Keywords: SAR interferogram, Northern Nagano Prefecture earthquake in 2014, subsurface rupture structure

Fault geometry on Miura-hanto fault group presumed by comparison of various seismic reflection records

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Miura-hanto fault group (MHFG) mainly appeared at the land area of Miura Peninsula, southern part of Kanto district and are consist from main and southern parts, both showing right-lateral slip with vertical displacement. The main part of the MHFG is divided into two parallel faults whose strikes are WNW-ESE, i.e. Kinugasa-Kitatake fault (north side) and Takeyama fault (southern side).
In a land area and a seaward extension of these faults, several seismic reflection surveys were conducted to elucidate fault geometries and those activities. Further long seismic survey line was set crossing at high angle with the trend of the MHFG from Sagami bay to Tokyo bay to reveal the geometry of the Philippine Sea plate’s upper surface.
Since spatial resolutions of these surveys arranged from several centimeter to several hundred meter order, it makes us possible to discuss a detailed fault geometry of MHFG from the sea bottom to the depth of the PHS plate boundary by careful comparing between these seismic profiles.
Then we estimated the location of Takeyama fault from the shallow to the deep by using a high-resolution chirp sonar image, a fine singe-channel profile, middle range multi-channel profiles and other previous seismic profiles derived in the study region.
As a result of careful examination on the seismic reflection profiles, bending of the sea floor and kink-like deformation structures of strata are recognized, implying the existence of a fault. In addition, the fault at the deeper depth is also configured from single and multi-channel profiles as reflection discontinuities. The location of this fault is correlated to the seaward extension of the Takeyama fault, and therefore, we judged the fault as the Takeyama fault. . This fault has the northward dipping, changing inclination angle from steep to gentle as increasing depth. In contrast, there are tilted reflections derived from the Philippine Sea plate (Ministry of education, Culture, sports, Science and Technology 2003). Based on the spatial relationship between Takeyama fault derived in this study and the deeper reflector, there is a possibility that these two faults might continue. However, since we can’t continually encompass all the reflections compared to the depth direction, we are planning on discussing it including the comparison with the velocity structure.

Keywords: Miura-hanto fault group, Sea area, Active fault, Seismic reflection survey

Electrical resistivity survey of subsurface structure of an active fault - A case study of the Gomura fault in Kyotango, Kyoto -

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The relationship between earthquake magnitude and displacement accompanying an earthquake was first proposed by Matsuda (1975) for Japanese Inlands. This formula has been widely used to estimate the magnitude of a large earthquake which will occur at a given fault-segment. However, many papers recently pointed out the generation of earthquakes with larger magnitudes than the estimated ones. Revealing subsurface structure of an active fault is not only an important key to overcome the inconsistency (The Earthquake Research Committee, 2010) but also an interesting academic theme.
Clear electrical conductivity 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 (e.g., Ritter *et al.*, 2005). The electrical conductivity distribution can provide a new image of the subsurface structure of an active fault.
A clear surface earthquake fault appeared associated with the 1927 Kita-Tango Earthquake in the Tango Peninsula of the northwestern part of Kinki district, Japan. This fault is named the Gomura fault and is one of the fault segments of the Yamada fault system.
We made an audio-frequency magnetotelluric (AMT) survey at twelve stations along a transection across the Gomura fault and obtained two-dimensional resistivity model (GMR model) along the line. The model is characterized by four conductive regions.
(1) Shallow sub-horizontal conductive layer (C1) between 160m and 300m in depth.
(2) Deep sub-horizontal conductive layer (C2) between 750m and 1200m in depth.
These layers are located to the east of a surface trace of the Gomura fault.
(3) Sub-vertical conductive zone (C3) beneath a surface trace of the Gomura fault.
(4) Weak and local conductive zone (C4) beneath a surface trace of the Go-seihou fault.
In this presentation, first we show MT responses for some typical resistivity structures which are expected to exist beneath an active fault, second explain some features of the GMR model, and finally interpret the GMR model with referring to the 1,300m-long borehole data.

Keywords: active fault, Magnetotellurics, Gomura fault

Geological and geomorphological surveys, geophysical surveys, and borehole surveys along the Gomura and Yamada fault zone, and these applicabilities and efficiencies for development of the active fault evaluation

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In the case of lacking the overlying sediments and cross-cutting relationships between the sediments and active faults, the fault activities were not identified clearly. In such case, the methodology of fault activity evaluation is needed to be improved. In our project commissioned by Secretariat of Nuclear Regulation Authority (S/NRA/R), we execute geological and geomorphological survey, geophysical survey, and borehole surveys along the Gomura fault zone ruptured during the 1927 Kita-Tango Earthquake and the Yamada fault zone located in the south of Gomura fault zone. Base on these surveys and its analysis, we organized these surveying technique and its applied condition for the evaluation of active fault, then we aimed for an establishment of the methodology for synthetic evaluation approach of active faults.

Keywords: fault activity evaluation, geological and geomorphological survey, geophysical explorations, borehole surveys, Gomura fault zone, Yamada fault zone

Estimations of fault locations based on Ground Penetrating Radar survey around the western river mouth of the Fuji river

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The 1854 Ansei Tokai earthquake presumably generated wide uplift around the western river mouth of the Fuji river, Shizuoka prefecture, Japan. The uplift indicates that the rapture area of the 1854 earthquake can extend from the Nankai and Suruga troughs to the Iriyamase fault. To forecast earthquake processes in the future, it is important to identify locations and activities of the Iriyamase fault.
We surveyed locations of the Iriyamase fault by using Ground Penetrating Radar (GPR) instrument on 4^{th}-8^{th} January, 2016. Because a strike angle of the Iriyamase fault is nearly north-south direction (Headquarters For Earthquake Research Promotion, HERP, 2010), most survey lines were set to be west-east direction, which is basically perpendicular to the fault. Length of the total survey lines are 13 km. The frequency of the used radio wave is 100 MHz. This spec can detect reflections of the layers about 5 m deep from the ground.
As a result, we found discontinuity of the layers at least at four locations on the survey lines within 2 km inland from the shoreline. There seem to be offsets at the discontinuity between the west and the east layers. The discontinuity extends just below filling, and the offsets are considered to be generated relatively late years. The locations of discontinuity are close to the Iriyamase fault estimated by HERP, and two of them are also close to locations of the faults estimated from seismic reflection survey for several tens to hundreds meters deep (Ito et al., 2014).
On the other hand, we also found the discontinuity at the north of Kambara junior high school and the east of old Ihara high school, which are apart from the locations of the Iriyamase fault. This indicates that the Iriyamase fault consists of splay faults as Ito et al. (2014) reported.

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Keywords: Ground Penetrating Radar, Iriyamase fault, 1854 Ansei Tokai earthquake

Continuation of Submarine Active Fault in the Suruga Trough towards Inland Area

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We discuss on continuation of submarine faults in Suruga trough to inland active faults based on the detailed submarine topographic map as well as field observation in the area along Fujikawa River. Many workers have considered that the Fujikawa-kako Fault Zone is the inland boundary of the Philippine Sea Plate. The fault zone is believed to be composed of active reverse fault traces with very high slip-rate as fast as 7m/1000 years. However, in spite of repeated paleoseismological field studies, concrete evidence for past activities of proposed active fault traces has not been so far found. The fault zone consists of two fault lines, namely east and west lines, and the east one following the eastern margin of the Habuna and Hoshiyama hills was first recognized by Tsuya (1940) as an arcuate fault scarp facing Mt. Fuji. We found similar faulted feature of the Habuna and Hoshiyama hills to the southwestern part of the outer rim of Taal caldera lake, Central Luzon, Philippines.
Therefore, we consider that the active faults composing the east line of the fault zone may be gravitational fault related to volcanic activity of Mt. Fuji. The submarine active fault in Suruga trough extends northward to the mouth of Yui river where Iriyama fault, the southern part of the west line of the Fujikawa-kakou Fault Zone is located. Active fault trace along the Iriyama fault is hardly recognizable due to its low slip-rate. We also newly found consistent left-lateral stream offsets along Minobu, Neguma and Tashirotoge faults previously known as thrust in the southern Fossa Magna zone between Itoigawa-Sizuoka Tectonic Line and Fujikawa river. In conclusion, it is necessary to collect more dependable evidence for discussion about location of the plate boundary in the northern margin of the Philippine Sea Plate.

Keywords: active fault, submarine active fault, Suruga trough, Fujikawa-kakou Fault Zone, plate boundary

