Active Fault Research for Better Preparedness for Earthquakes

Program and Abstracts

HOKUDAN International Symposium on Active Faulting

In Commemoration of the 30th Anniversary of the 1995 Great Hanshin-Awaji Earthquake

January 23rd--25th, 2025
On the Web

Operation Committee of
Hokudan International Symposium on Active Faulting 2025

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Hokudan International Symposium on Active Faulting 2025

Introduction

HOKUDAN 2025: Active fault research for better preparedness for earthquakes

Preparedness is the key to mitigate earthquake disasters. We are not able to prevent or to predict an earthquake that may hit us at any moment. However, we are able to learn about the characteristics of the earthquake through the history and geology. Then we prepare for the hazard with the knowledge.

1995 Hyogo-ken Nambu earthquake and the Hanshin-Awaji earthquake disasters were so devastating because of the lack of the knowledge. The damaged areas in 1995 were not prepared well for the hazards owing to the lack of historic records and to the insuNicient information on the geology of earthquakes. There was no historic record on very strong shaking in Kobe and in Awaji island. The Nojima fault on Awaji island, the surface rupture during the 1995 earthquake had been mapped but its earthquake potential was not investigated. Studies on active faults had advanced since 1980s, but the results were not well disseminated for preparedness. Strong motion seismology had waited for the 1995 earthquake to start the development.

The 1995 earthquake and disasters changed the science and the politics on earthquake hazards and disasters greatly. Long-term evaluation of earthquake sources, forecasts of earthquakes from know sources, and estimation of ground motion realized the probabilistic hazard maps of Japan in 2005. Preparedness based on forecasts became the key for disaster mitigation after 1995 disasters. In 30 years, scientists together with engineers, national and local governments, and practioners in various specialities sought after safer society for earthquake hazards. Like in Japan, many areas in the world learned a lot from earthquake disasters in 1980s and 1990s have promoted earthquake safety. However, unexpected hazards as pure suprises such as 2011 Tohoku, 2023 Kahramanmaras, and 2024 Noto Peninsula earthquakes attack unprepared areas and result in devastating disasters. Obviously, our knowledge on earthquakes, evaluation of hazards, and public dissemination are not suNicient. We need to study more on active faulting and its consequences and disseminate the information to establish and improve preparedness in earthquake prone areas. Hokudan 2025 will be an important opportunity to learn about recent disasters, frontiers of studies on active fault research, and ways to make our communities safer from earthquakes.

Hokudan International Symposium on Active Faulting 2025

program

Thursday, January 23rd

Recent disastrous earthquakes and active faults

in JST (UT+9) (Chaired by J. Bruce H. Shyu)

09:00--09:02 Okumura, K.: Opening address

09:02--09:25 Okumura, K.: January 1, 2024 Noto Peninsula Earthquake: its outline and coastal uplift

09:25--09:50 Wang, Yu, Wu S-H., Li, Y-Y., Cheng, W-Sa., Duan, Siang, Saw Myat Min, Ei Mhone Nathar Myo, and Shyu, J. Bruce H.: The co-seismic and post-seismic cross-fault deformation of the 2022 eastern Taiwan earthquakes

(Chaired by Wang Yu)

09:50--10:15 Shyu, J. Bruce H.and Wang, Yu.: Lessons learned from the 2022 and 2024 eastern Taiwan earthquakes for future seismic hazard assessments

(Chaired by Wang Yu)

10:15--10:40 Cinti, F.R. and Pantosti, D.: Findings and issues for paleoseismologists from the destructive 2016 Central Italy earthquake sequence

10:40--11:05 Lombardi A.M., Cinti F.R., and Pantosti D.: Probability assessment of next fault ruptures from paleoseismological data in Central Apennines (Italy)

11:05--11:15 break

(Chaired by K. Okumura)

11:15--11:40 Özdemir, E. Kürçer, A., Elmacı, H., Güven, C., Güler, T., Avcu, İ., Olgun, Ş., Avcı, H.O., Aydoğan, H., Yüce, A.A., and Özalp, S. The assessment of February 06 2023 Pazarcık (Kahramanmaraş) earthquake (MW 7.8) on the East Anatolian Fault Zone in Türkiye within slip distribution and the structural features

11:40--12:05 Meghraoui, M., Çakır, Z., Kariche, J., Toussaint, R., Provost, F., Karabaçak, V., Sbeinati. R., Altunel, E., and Nemer, T.: The 2023 Mw 7.8 Kahramanmaras earthquake rupture increases failure potential along the northern Dead Sea Fault

12:05--12:30 Taşkın, B. and Yazar, M.: The Aftermath of 2023 Kahramanmaraş, Türkiye Earthquakes.: Ground Motions, Site Effects and Structural Failures

12:30--12:55 Kondo, H.and Özalp, S.: Paleoseismological Researches Before and After the 2023 Destructive Earthquakes on the East Anatolian Fault System

New findings and progress in active fault research 1

12:55--13:20 Malik, J. N., Dhali, M., Gadhavi, M. S.,Prabhat, K., Ansari, M. A., Sharma, N. K., Srivastava, E., Kumaiya, M., and Sahoo, S.: Surface rupture signatures of historical earthquakes from Kumaon, Central Himalaya.: Implications for Seismic Hazard Assessment

Friday, January 24th

New findings and progress in active fault research 2

in JST (UT+9) (Chaired by T. Azuma)

09:00--09:25 Ikeda, M. and Onishi, K.: Spatial transition of rupture behavior along the Median Tectonic Line active fault zone in Shikoku, Japan

09:25--09:50 Ogami, T., Maruyama, T., Tara, K., Kazui, N., Kubo, T., Mukaiyama, K., Hosoya, T., and Goto, S.: Offshore active fault survey on Futagawa Fault Zone, Kyushu, southwestern Japan

09:50--10:15 Ando, R. Fukushima, Y. Yoshida, K. and Imanishi, K.: Nonplanar Fault Geometry Controls the Spatiotemporal Distributions of Slip and Uplift.: Evidence from the Mw 7.5 2024 Noto Peninsula, Japan, Earthquake

10:15--10:40 Nishimura, T. and Ueda, T.: Long-term forecast model for crustal earthquakes using geodetic data in Japan

10:40--11:05 Chen, Cheng-Hung and Shyu, J. Bruce H.: Offshore seismogenic structure database of the Taiwan Earthquake Model (TEM)

11:05--11:15 break

(Chaired by D. Pantosti)

11:15--11:40 Audemard, F. A. and Pousse-Beltrán, L.: The first Amerindian earthquake victim, swallowed by a Boconó Fault open-crack, at the Aroa Range foothills, Yaracuy state, Venezuela

11:40--12:05 Audemard M., F. A., Diederix, H., Fonseca P., H. A, Jiménez, J., Mora-Páez, H., Bohórquez-Orozco, O., Gómez-Hurtado, E., Aguirre, L. M., Escobar-Rey, L. K., López-Isaza, J. A., Muñoz, O., González, D., Martínez, G., Ramírez, J., Tique, Y. P., Barragán, W., Idárraga-García, J., and Rendón-Rivera, A.: Recent paleoseismic investigations by trenching of the major Algeciras Fault, Eastern Cordillera of Colombia

12:05--12:30 Rachman, M. G., and Shah A.A.: Mapping Active Tectonic Deformation Domains of SE Asia.: Implications for Earthquake Hazards

12:30--12:55 Okumura, K., Pokhrel, P. and Sapkota, M.N., Kondo, H., Koketsu, K., Miyake, H., and Suzuki, H.: Rupture History of the Himalayan Frontal Thrust near Bagmati River crossing in Central Nepal and the Future Scenario of Earthquake and Ground Motion Hazards for Kathmandu

12:55--13:20 Nakata, T. and Shimazaki, K.: Reexamination of historical coseismic uplifts of Murotsu Port, Kochi Prefecture and the time-predictable model for large earthquakes

Saturday, January 25th

Reminiscence of our deceased leaders in active fault research

in JST (UT+9) (Chaired by K. Okumura)

09:00--09:15 Azuma, T.: In memory of Professor Yoko Ota

09:15--09:30 Tstsumi, H.: In memory of Professor Robert S. Yeats

09:30--09:45 Meghraoui, M., Klinger, Y., and Van der Woerd, J.: In memory of Professor Paul Tapponier

09:45--10:00 Nakata, T.: In memory of Professor Tokihiko Matsuda “Father of active fault studies in Japan”

10:00--10:10 break

Hazard analyses of active faults

(Chaired by S. Toda)

10:10--10:35 Nishizaka, N. and Tsuji, T.: Developing probabilistic fault displacement hazard analysis frameworks for distal sites

10:35--11:00 Fujiwara, H.: Advancements in National Seismic Hazard Maps for Japan

11:00--11:25 Rockwell, T.K.: Short-term variations in earthquake production in the southern San Andreas fault system due to lake level variations in Lake Cahuilla, Salton Trough, California.: Implications for short-term slip rate variability

11:25--11:50 Schwartz, D. P.: Why the Probability of Refining Regional Earthquake Probabilities in the San Francisco Bay Region is Low--and Will Remain That Way

Hokudan International Symposium on Active Faulting 2025

abstracts

January 1, 2024 Noto Peninsula Earthquake: its outline and coastal uplift

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The January 1, 2024 Noto Peninsula Earthquake (Mw 7.5) struck central Japan in new year day afternoon at 16:10JST. Maximum intensity of 7 in JMA scale was recorded exposing more than 100000 people to intensity 6+ and 7. 462 fatalities and 1810 casualities have been reported. More than 30000 houses were severely damaged by strong shaking and liquefaction. The source fault of the main shock runs 1 to 10 km offshore along the north coast of Noto peninsula and continue NE under the sea for about 150 kilometers. The southeast-dipping reverse faults are located right beneath the northern coastal areas of the Noto peninsula and the slip resulted in very strong ground motion and uplift of the coastal area. Up to 2.7 g PGA and 100 to 150 cm/s PGV were recorded in several stations and caused severe structural damages and many coseismic mass movements. Liquefaction hazards were significant in coastal lowlands and reclaimed ground within 200 km from epicenter. Tsunami run-up of 1 to 6 meters are observed in the area surrounding Noto peninsula.

The coastal coseismic uplift was observed on northern and western coasts of the peninsula. The northern coast is on the hanging wall of the southeast dipping reverse fault which ruptured sea bottom by 1 to 3 meters. The shorter distance between sea-floor traces and coastline corresponds to the coastal uplift amount. The amount is the biggest around the northwest corner of the peninsula to reach 5 meters. The uplift of the western coast decreases sharply towards south and less than a meter along 20 m long coastline. West coast uplift may be related to restraining termination of the fault with large right-lateral strike slip component. This area is also characterized by big swarm of aftershocks. The southern coast on Toyama bay on the other side does not show significant uplift.

Middle to Late Pleistocene marine terraces, MIS 5e and before, surround the Noto peninsula. Though the coasts of largest uplift lack Pleistocene marine terrace for erosion, MIS 5e terraces are 50 to 100 meters above sea level in the central part of the northern coast. In the western and southern coasts, they are 20 to 50 meters and 20 to 80 meters respectively. The uplift of the northern coast with nearby offshore faults indicated coseismic uplift with tsunamis. However, there are only rather distal (10 kilometers or more) offshore faults along the coastline which faults do not account for coastal uplft.

The co-seismic and post-seismic cross-fault deformation of the 2022 eastern Taiwan earthquakes

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Li, Yi-Yu (Department of Geosciences, National Taiwan University)
Cheng, Wai San (Department of Geosciences, National Taiwan University)
Duan, Siang (Department of Geosciences, National Taiwan University)
Saw Myat Min (Department of Geosciences, National Taiwan University)
Ei Mhone Nathar Myo (Department of Geosciences, National Taiwan University)
Shyu, J. Bruce H. (Department of Geosciences, National Taiwan University)

The 2022 Mw 6.4 and 6.8 Guanshan-Chihshang earthquakes resulted in prominent surface ruptures, particularly along the Yuli fault in central Longitudinal Valley, eastern Taiwan. These surface ruptures and ground deformations were documented by a series of field and geodetic surveys after the mainshock, and both results showed a clear oblique left-lateral deformation pattern on the surface. In many sections of the rupture, the amount of left-lateral deformation measured right across the surface rupture is significantly smaller than the deformation estimated from the nearby geodetic result, pointing out that clear off-fault deformation occurred in the shallow part of the Yuli fault. Our repeating cross-fault measurements also show significant shallow after-slip along the Yuli fault within the first 3 to 4 months after the mainshock, especially in the section where the clear off-fault deformation occurred co-seismically. In the section where the Yuli fault transects through the town of Yuli, the amount of cross-fault after-slip is close to, or even higher than the co-seismic cross-fault displacement we mapped in the field. Such shallow after-slips were also observed along the main fault trace in the 2014 South Napa earthquake, and likely represent the shallow elastoplastic behavior of the sub-vertical fault in the young alluvial sediments. Such an effect may impact our observation and interpretation in the paleoseismological study, especially at the fault where the trench investigations were limited. Hence, we suggest that it is necessary to take these off-fault deformations into account, especially when estimating the fault offset from the trench records.

Lessons learned from the 2022 and 2024 eastern Taiwan earthquakes for future seismic hazard assessments

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Taiwan is located along the plate convergence belt between the Eurasian and Philippine Sea plates. This collisional tectonic setting has produced numerous active faults and frequent earthquakes that pose great seismic hazard for the island. As a result, there have been many efforts that focus on identification and characterization of seismogenic structures for the assessment of future earthquake hazard. For example, the multi-disciplinary "Taiwan Earthquake Model" (TEM) project team has constructed a complete and updated seismogenic source database, and such database has been utilized in building probabilistic seismic hazard analysis (PSHA) models for Taiwan.

Nonetheless, a few recent earthquakes in eastern Taiwan have illustrated the complexity of seismogenic characteristics of the island, and pointed out the challenges for further understanding, assessing, and mitigating seismic hazards in the future. For instance, the 2022 Mw7.0 Chihshang-Guanshan earthquake series occurred on the Central Range fault system, which has previously been identified. However, the surface rupture and deformation patterns suggest that the fault system is much more complex than previously thought. The fault system's close interaction with another major fault also shows the importance of identifying and calculating such interactions in terms of future earthquake potentials. The 2024 Mw7.4 offshore Hualien earthquake, on the other hand, illustrated the importance of offshore seismogenic structures, which have not yet been widely analyzed or incorporated into PSHA models. All of these issues constitute the next most important questions to be solved for future seismic hazard assessment studies not only for Taiwan, but also for earthquake prone regions worldwide.

Findings and issues for paleoseismologists from the destructive 2016 Central Italy earthquake sequence

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Pantosti, D. (Istituto Nazionale di Geofisica e Vulcanologia – daniela.pantosti@ingv.it)

The 2016 normal faulting earthquake sequence struck and strongly devastated a wide region of Central Italy. The sequence lasted for several months and was composed of 3 mainshocks: Aug 24 Mw 6.0, Oct 26 Mw 5.9, Oct 30 Mw 6.5. This latter earthquake is the strongest Italian seismic event since the 1980 Mw 6.9 Irpinia earthquake. The sequence involved two adjacent NW-trending and SW-dipping normal fault systems, i.e. Vettore-Bove and Mts. Laga. Based on trenching literature, the activated systems were previously considered independent and quiescent active segments (Galadini and Galli, 2003).
The first shock caused a ≈5 km of surface faulting with 0.13 m average throw (Pucci et al., 2017); similar effects were observed for the 26 Oct event (Figure 1). Conversely, the Mw 6.5 event produced a ≈22 km long, complex, and impressive surface faulting pattern, with average throws of 0.44 m, locally >1.5-2 m. These ruptures involved both mapped faults and a few previously unknown strands and surprisingly overprinted those that occurred during the two previous mainshocks (Villani et al., 2018; Figure 1). This proves that also for normal kinematics, surface ruptures can re-occur on the same portion of a fault system within a few days/months: a scenario that has been seldom documented so far.
Overall, the ruptures from the three mainshocks extended for a total length of ≈28 km involving both steeply exposed limestone bedrock and loose deposits.
The 2016 earthquake sequence poses new questions, revives old issues, and opens new perspectives particularly relevant for paleoseismology on normal faults, especially in young tectonically active areas with moderate seismicity, such as central and western Europe.
Below are some of the scenarios that we may face in interpreting paleoseismic trenches that will be discussed in this presentation.

1) Can the 2016 surface ruptures be considered surface faulting (i.e., surface expression of the seismogenic fault at depth)? Given the steep and rough topography of the epicentral area, could these rupture traces be amplified by slope instability and gravity? or given the complex upper crustal tectonic setting, could these ruptures be on a superficial fault plane disconnected from the seismogenic source?
2) What is the significance of the paleoearthquake record that we interpret as due to discrete slip events; can it actually represent the cumulative effect of more events very close in time (Figure 2)? which is the paleoearthquake size and time interval resolution in a trench exposure?
3) Given the complexity of the deformation zone that may be up to 3 km-wide, including slip partitioned on main ruptures and subsidiary splays (Figure 1), trenching can be performed on both types of splays. Is the slip observed along individual splays characteristic in space and time? Trenching on subsidiary splays reveal the fault seismic history, can this history be considered complete and can provide insights on the fault extent and size of future earthquakes? Can the long-term morphological signature provide clues on future earthquakes?
4) Were the expected segment boundaries between the two involved adjacent fault systems (i.e., Vettore-Bove and Laga Mts.) violated during the 2016 earthquake?

References
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Galadini F. and Galli G. (2003). Ann. of Geophys. https://doi.org/10.4401/ag-3457
Pucci, S. et al. (2017). Geophys. Res. Lett. https://doi.org/10.1002/2016GL071859
Villani, F., et al. (2018). Sci. Data. https://doi.org/10.1038/sdata.2018.49

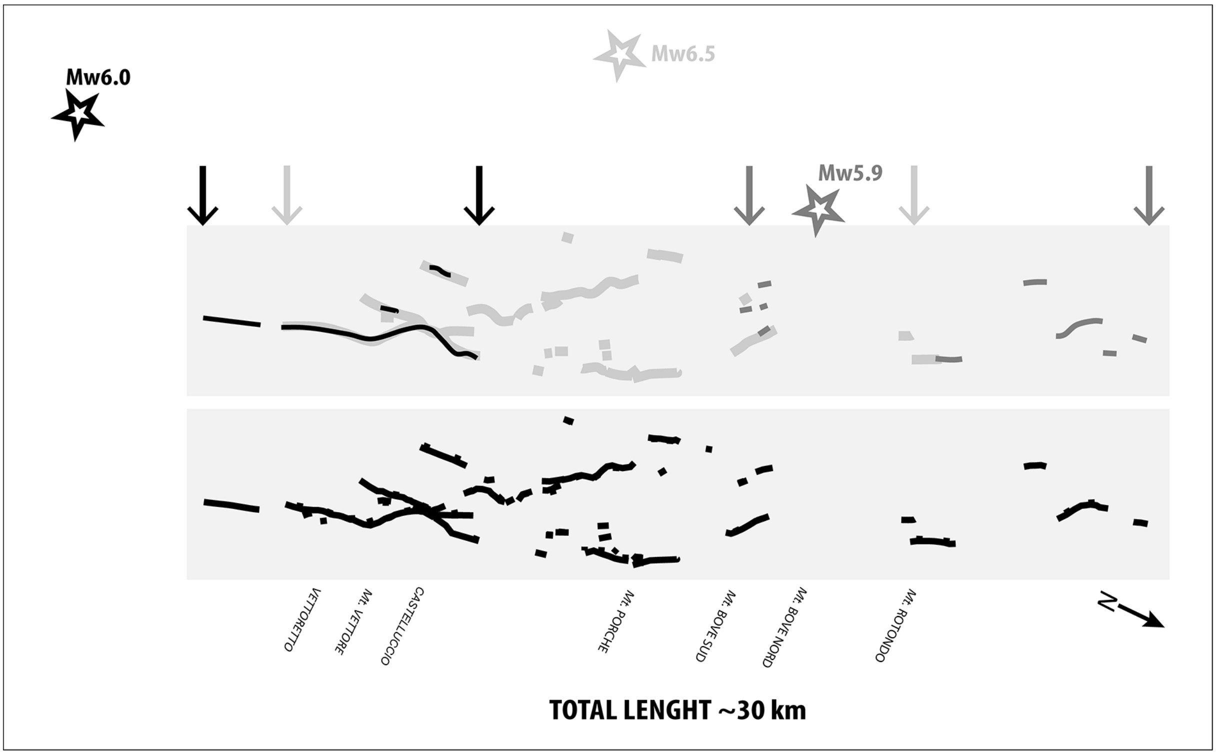

Figure 1. Simplified map of the 2016 surface rupture traces. In the upper panel, the traces with different gray tones indicate the ruptures produced by the three individual mainshocks of the earthquake sequence (stars) occurring along the whole fault system, but partitioned in time. Note that the Mw6.5 mainshock ruptured the central portion of the fault system previously “locked”, and partly override splays broken during the previous mainshocks. Data from Villani et al. (2018).

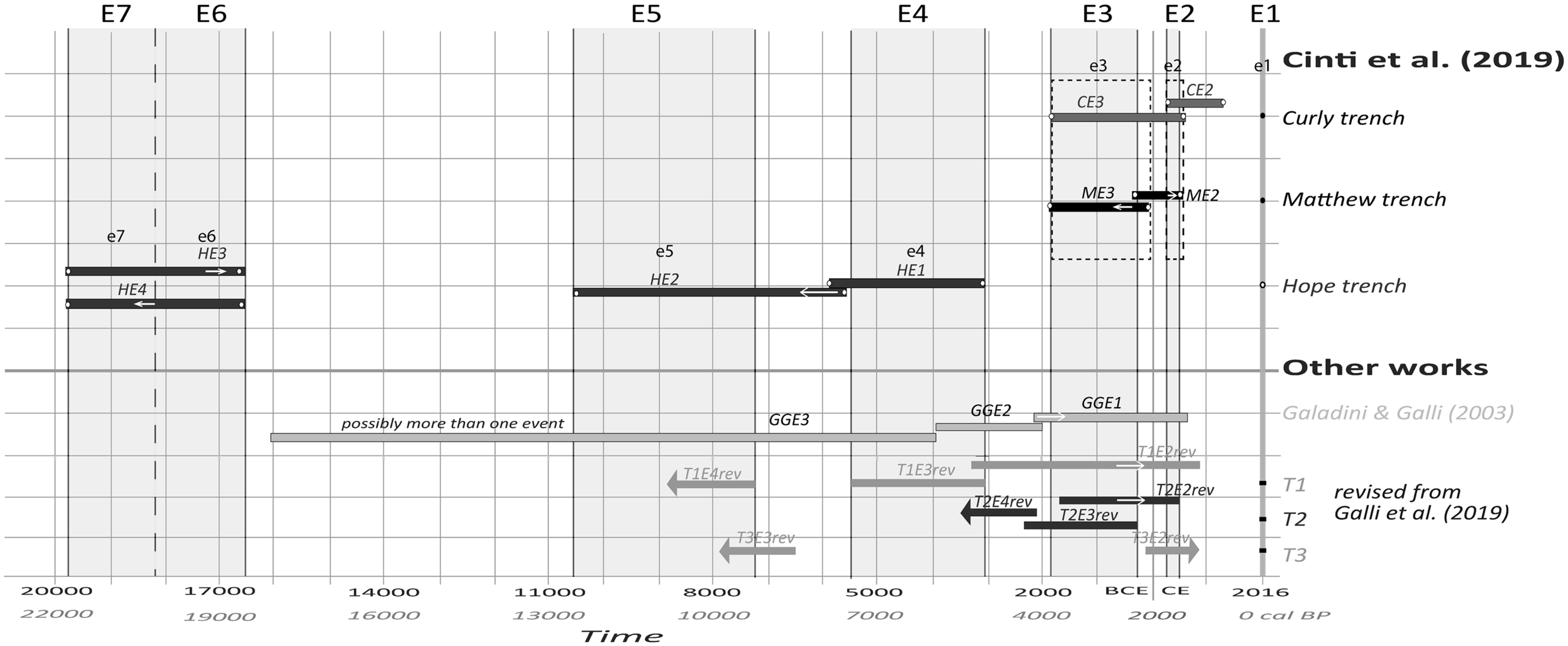

Figure 2. Summary of the timing of events obtained from the trenches across the 2016 surface faulting presented in different papers (modified from Cinti et al., 2019). Note that the data from Galadini and Galli were collected years before the occurrence of the 2016 earthquake sequence. Correlated events from all the data sets are referred to as E1 (i.e., 2016) to E7 from the youngest to the oldest. Black circles refer to the 30 October 2016 earthquake. Horizontal bars show the uncertainties on the age of the events, and white arrows point to the preferred portion of the age interval (for details see Cinti et al., 2019). The shaded vertical bands represent the preferred correlations, based on additional stratigraphic considerations when delimited by dashed lines.

Probability assessment of next fault ruptures from paleoseismological data in Central Apennines (Italy)

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By using paleoearthquakes histories during the past 27,000 yrs, we explore earthquake occurrences and earthquake rupture forecasts both on individual faults and at regional scale in the Central Apennines in Italy. More details on this work can be found in Lombardi et al. (2024, under revision).
Paleoseismological trenching data for 16 faults published until 2021 were used to build a new database of surface faulting earthquakes. This database differs from the previous ones presented in Cinti et al. (2021) because it includes the published records of trench data mostly without any revision. Revision was applied only when data were presented by the authors as merged from different individual trenches, and thus they underwent a disaggregation procedure. This procedure was foreseen to avoid bias in the rupture history given by the author's trench data correlation. The resulting dataset comprises 16 faults, 67 trenches, and 198 individual trench paleoearthquakes.
The event ages from distinct trenches on each fault were used to construct all possible individual fault rupture scenarios for each of the 16 faults. Scenarios were obtained applying the probabilistic aggregation method proposed by Cinti et al. (2021), which searches for possible fault event age intervals intersecting paleoearthquake ages from different trenches along the same fault. We assign a uniform probability distribution to the maximum age range of the event, identified by the C14 calibrated data with two standard deviations uncertainty. The adoption of a uniform distribution allows us to rule out any bias on results, coming from more sophisticated, but subjective, PDFs without giving up a probabilistic treatment of data.
We selected a total of 33 scenarios for the 16 faults (figure 1) that allow us to obtain information on past surface faulting earthquakes (M6+) in the studied region. The 33 scenarios were used to infer the distribution in time of interevent times (IETs) of the whole region from 106 simulated earthquake time histories of individual faults. The temporal trend of the median IET values (MIET) for all the faults, shows a change point at about 6000 BCE marking two periods with MIET close to 120 and 480 years, for the more recent and the less recent periods, respectively. Since 6000 BCE the dataset appears to have quite stable statistical properties and smaller uncertainties, therefore we statistically analyzed only this time window.
The rupture recurrence on individual faults was explored by estimating mean IETs on 106 simulated fault rupture scenarios. The average recurrence varies from several hundreds to few thousands of years. The probability of future events varies considering all sources of uncertainty, related to both ages and rupture temporal models; we find that they depend on basic features of the temporal model and on the relation between the elapsed time and the mean interevent time. We employed two temporal models as representative of the whole class of renewal models and of different possible time-dependent behaviors: a reference Poisson process and a Brownian Passage Time model (Ellsworth et al., 1999). We compute the probabilities of occurrence for the next event, both for individual faults (figure 2) and at regional scale, highlighting the effects of time-dependent and time-independent

occurrence hypothesis on earthquake forecast assessment. At a regional scale, we cannot exclude the simplest possible model, i.e. the Poissonian behavior that provides quite stable probabilities of future events close to 27% in the next 50 years. For all 16 individual faults there is not a preferred model. By comparing the three models for ΔT= 50 years, we found the largest probabilities for the Poisson model for Fucino (F3), Paganica-San Demetrio (F8) and Sulmona (F16) faults, having the smallest estimated average interevent times. Conversely, the periodic model identifies Monte Ocre (F2), Aremogna Cinque-Miglia (F15) and Sulmona (F16) as the most probable faults, since the elapsed times are larger than the average interevent times. Note that the probabilities in figure 2 are not intended to represent absolute estimates; they strongly depend on choices about the occurrence model and data treatment, but help us to understand the sensitivity of regional and fault hazard assessment to all sources of uncertainty.

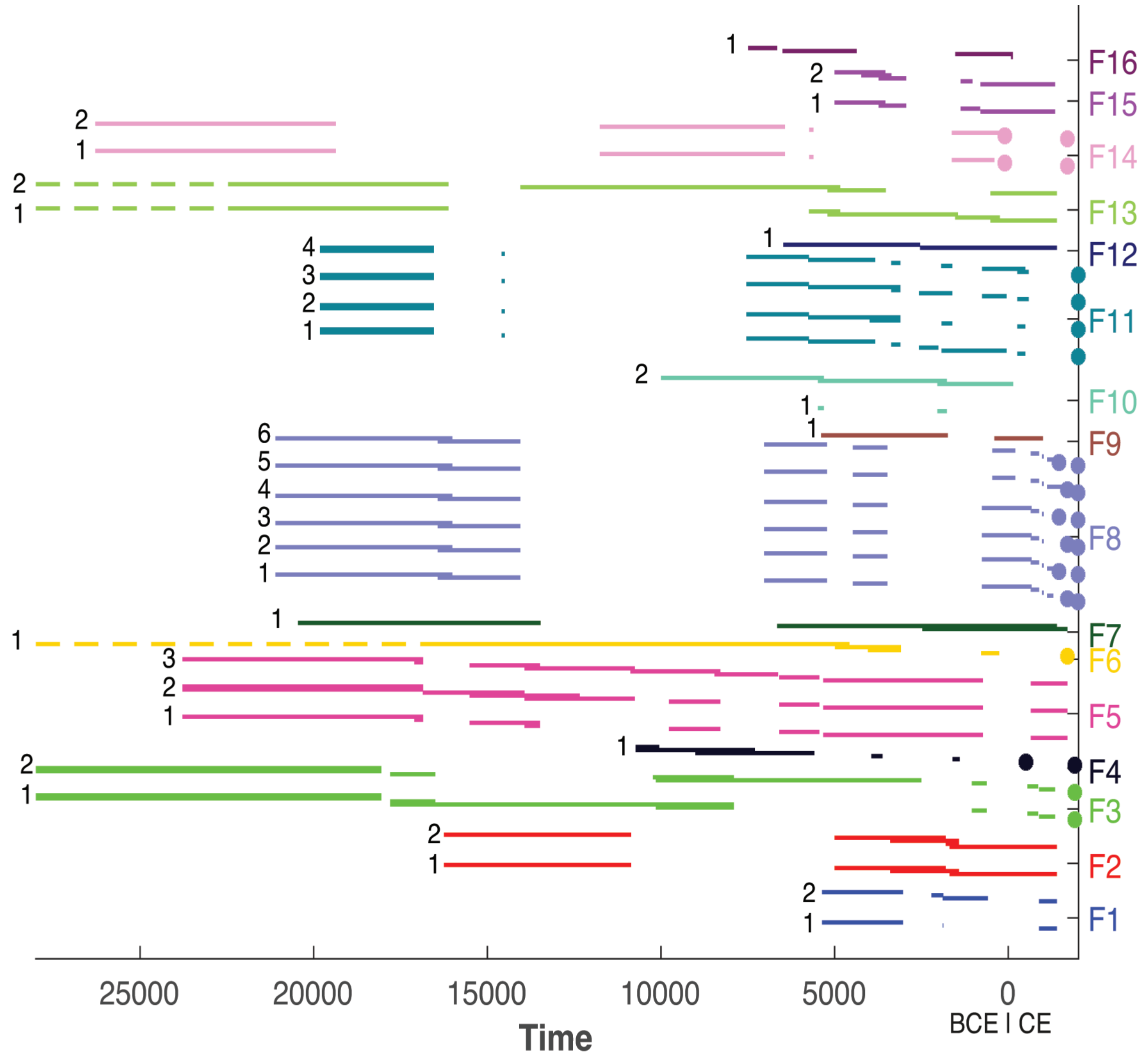

Figure 1: Chronogram of the scenarios computed and selected for faults F1-F16 (see also map in figure 2) from the paleoearthquake dataset of Central Apennines (Lombardi et al., under revision). The number of scenarios for individual faults is indicated on the left, ranging from 1 to 6. The dots refer to paleoearthquakes correlated with events in the historical catalogs.

References

Cinti et al., 2021. Tectonophysics, https://doi.org/10.1016/j.tecto.2021.229016

Ellsworth et al., 1999. U.S. Geol. Surv. Open File Rep. OF99-520

Lombardi et al., 2024. Paleoearthquakes modeling and effects of uncertainties on probability assessment of next fault ruptures: the case of Central Italy surface faulting earthquakes, JGI, under revision.

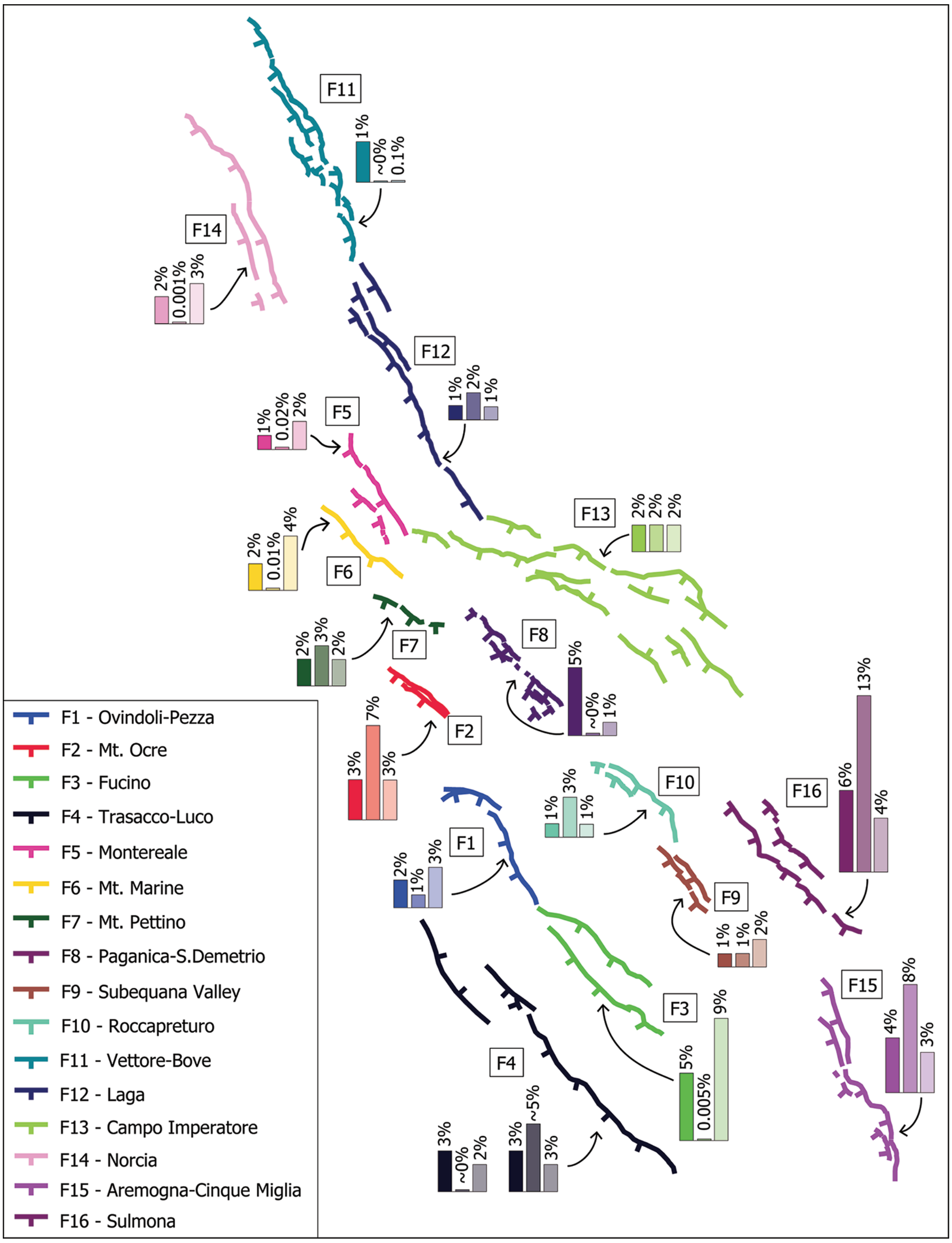

Figure 2: Values of probabilities for ΔT=50 yrs, calculated for each of the 16 faults, for Poisson, quasi-periodic BPT and cluster BPT models (darker to lighter histogram columns, respectively) (Lombardi et al., 2024 under revision). Fault F4 has two different calculations considering two possible TL (the 1915 or 508CE as it ruptured in 1915 only sympathetically). The same is for Fault F10 but results are very similar and thus represented as a single histogram.

The assessment of February 06 2023 Pazarcık (Kahramanmaraş) earthquake (MW 7.8) on the East Anatolian Fault Zone in Türkiye within slip distribution and the structural features

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On the 6th of February 2023, Türkiye witnessed two destructive earthquakes in an interval of 9 hours. The first earthquake occurred in Pazarcık had a magnitude of 7,8 on the East Anatolian Fault Zone (EAFZ). The second earthquake nucleated in Ekinözü, had a magnitude of 7,6 on the eastern end of the Çardak Fault. 11 cities were directly affected by these massive earthquakes and more than 50.000 people lost their lives. February 6, 2023, Pazarcık (Kahramanmaraş) and Ekinözü (Kahramanmaraş) Earthquakes occurred with the left-lateral strike-slip faulting mechanism. After the Pazarcık earthquake MTA launched a survey that included both ground and aerial investigations. This research was to observe the surface rupture; map and identify the slip rates and reveal new evidence of the EAFZ's segment structure.

In addition to the land surveys, which were 410 stations in total, in which slip measurements both vertical and horizontal has gathered elaborately and recorded, also aerial survey has been conducted with MTA-UAV. Considering the epicenter of the mainshock of the Pazarcık earthquake and the temporal and spatial distribution of the aftershocks, it can be said that the rupture started on the Tetirlik Segment of the EAFZ and progressed on multiple segments in the EAFZ.

As a conclusion to the field and aerial surveys; the Yarpuzlu restraining double bend, Erkenek, Pazarcık, Amanos, Serinyol and Tetirlik segments of the EAFZ ruptured resulting a total of 385 km.surface rupture. According to the distribution of aftershocks which were recorded at the south of the Tetirlik segment, it has been determined that a fault section approximately 20 km long most probably ruptured at depth but did not produce a surface rupture. The maximum displacement after this earthquake has been recorded as 7,2 ±1 m. on the Pazarcık Segment.

The 06 February 2023 Pazarcık (Kahramanmaraş) earthquake revealed that the EAFZ is a transform fault that created a multi-segment surface rupture. Therefore these consecutive earthquakes may have transferred stress to the faults in the vicinity of East Anatolian part of Türkiye which has seismic gaps in their earthquake generation cycle.

Keyword: East Anatolian Fault Zone, Pazarcık (Kahramanmaraş) Earthquake,Surface Rupture, Fault Segmentation, Displacement

The 2023 Mw 7.8 Kahramanmaras earthquake rupture increases failure potential along the northern Dead Sea Fault

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The 6th of February 2023 earthquake sequence along the East Anatolian Fault (EAF, Mw 7.8) and Çardak fault (CF, Mw 7.6) in southern Turkiyereveals the importance of seismic gaps and fault segments interaction. Both large earthquakes show shallow hypocentres (<15 km), strike-slip mechanisms, with NE-SW trending Golbaşi-Kahramanmaras-Karasu fault segments reaching ~350 km and E-W trending Çardak fault along 150 km. Field investigations of surface ruptures, aided with Sentinel 2 image correlation, document the coseismic slip distribution, reaching 8 m on the Pazarçik segment and 4.1 m on the Kirikhan segment. Prior to the recent seismic sequence, our field investigations from 2003 to 2007 allowed a detailed map of the EAF fault from Golbaşi to Antakia and showed ~ 4.3 m to > 1300 m cumulative left-lateral slip of stream channels south of Kahramanmaras. According to contemporaneous historical accounts, the 29 November 1114 earthquake that severely affected Antakia, Marash (Kahramanmaras), Adiyaman and Urfa (Sanlurfa) with about 40,000 victims, is the largest penultimate event and may represent an analogue to the 2023 Mw 7.8 earthquake. An evidence of fault interaction between the EAF and Dead Sea Fault (DSF) comes with the southward migration of large historical earthquakes from the CE 1114 seismic event to CE 1138, 1156, 1170, and 1202 large earthquakes along the northern segments of DSF. The modelling of the seismic slip deficit and stress transfer illustrates a significant seismic hazard with the potential for a failure increase and a ~ 21 year-time clustering of major events along the northern DSF segments.

Keywords: 2023 Earthquake sequence, East Anatolian Fault, Dead Sea Fault, Stress Transfer modelling.

The Aftermath of 2023 Kahramanmaraş, Türkiye Earthquakes: Ground Motions, Site Effects and Structural Failures

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On February 6, 2023, the southeastern region of Turkey was shaken by three consecutive earthquakes, the first of which occurred at 04:17 local time early in the morning. The earthquakes took place on the left-lateral strike-slip East Anatolian Fault (EAF), which forms the transform-type tectonic boundary between the Anatolian Plate and the northward-moving Arabian Plate. In addition to Türkiye, the earthquakes were felt across a wide area, including Syria, Lebanon, Israel, Jordan, Cyprus, Egypt, Iraq, and Iran. According to official data, 53,537 people lost their lives in Türkiye and 8,476 in Syria, and more than 122,000 in total were injured. The earthquakes are reported to have an intensity of XII according to the Modified Mercalli scale, causing damage in an area of 350,000 km2 and affecting 14 million of people. Table 1 summarizes the sequential events and their characteristics.

Table 1. February 06, 2023 Kahramanmaraş Earthquakes

Table 1. February 06, 2023 Kahramanmaraş Earthquakes

	06.02.2023 - Pazarcık 	**06.02.2023 - Nurdağı** 	**06.02.2023 - Elbistan** 
Time (GMT)	01:17	01:28	10:24
Magnitude (M_w)	7.8	6.6	7.6
Latitude (N)	37.288	37.304	38.089
Longitude (E)	37.043	36.920	37.239
Depth (km)	8.6	6.2	7.0
No.of Records	360	143	370
PGA (cm/s^2)	2178.7 (EW)	454.2 (NS)	635.5 (NS)
PGV (cm/s)	212.9* (EW)	44.6 (UD)	170.8 (NS)
PGD (cm)	262.2* (UD)	214.4 (UD)	91.0 (EW)
Strike 1 & 2 (⊠)	233 / 140	300 / 187	358 / 90
Dip 1 & 2 (⊠)	74 / 77	70 / 43	73 / 86
Rake 1 & 2 (⊠)	18 / 168	-128 / -30	174 / 13

Reconnaissance field investigations, including ITU teams, were initiated on the third day after the quakes in the region. Liquefaction in the form of soil ejecta and excessive ground settlement were observed in Doğanşehir, Gölbaşı, Dulkadiroğlu, Türkoğlu, Dörtyol, İskenderun and Antakya, which caused overturning of buildings, electric poles and minarets, extreme foundation settlements, rupture of buried pipelines. It was observed that the water content of some springs decreased and disappeared completely due to the significant surface offset and ground deformations.
Strong ground motions in many locations exceeded the spectral acceleration levels defined in the

Turkish Building Seismic Code (2018) for the design level earthquake (475-year return period), and in some locations, for the maximum considered earthquake (2475-year return period) level. In these regions, many buildings suffered total or partial collapse and infrastructure were heavily damaged.

One of the most unusual aspects of these earthquakes was that the vertical accelerations were extremely high, in some locations even higher than the horizontal components. This phenomenon is worth reevaluating, specifically during the design of bridges, viaducts and structures with long cantilevers, which are vulnerable to vertical excitations.

Paleoseismological Researches Before and After the 2023 Destructive Earthquakes on the East Anatolian Fault System

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The Mw 7.8 and Mw 7.5 earthquakes produced by the East Anatolian fault system (EAFS) caused severe damages and casualties in and around the southeastern Turkey and Syria. Geological Survey of Japan and MTA have collaboratively worked on the EAFS since 2014 in order to map active faults, obtain paleoseismological data for long-term forecast, and understand the recurrence of past multi-segment earthquakes. We here briefly introduce some results of our joint research project before and after the 2023 earthquakes.

In 2014, we have started paleoseismological research on the southern section of the EAFS. The first paleoseismic trench site was selected at the Kartal site, which is about 25 km east of Kahramanmaraş. We opened two test trenches across the EAFS at the Kartal site, and identified 5-6 events but very few carbon dating samples were collected. Once the project suspended, and the joint project re-started in October 2022. We then decided to re-excavate the Kartal site for better constraint of individual paleoearthquakes and offset reconstruction based on additional 3D trenches.

On 6th Februayry 2023, the first Mw 7.8 earthquake occurred on the southernmost section of the EAFS. About nine hours later, some of the branch faults along the EAFS, Çardak fault and Doğanşehir fault caused the Mw 7.5 earthquake. Immediately after the occurrence of the earthquakes, we collaboratively worked on collecting source fault information as emergency response. After publication of post-earthquake airphotos and satellite photos on the web site by HGM, General Directorate of Mapping in Turkey, we started mapping of surface ruptures and measurement of displacement based on photogrammetric interpretation. The first report on the source faults of two respective earthquakes appeared on GSJ web site on 22th February, and the sixth report as final version appeared on 20th March. MTA also independently carried out the surface rupture mapping in the field. We thus quickly reported on the spatial distribution of primary surface ruptures and slip distribution along the faults.

In October 2023, we re-visited the Kartal site for re-excavation of the refilled 2014 trenches and additional excavation of 3D trench for offset reconstruction (Kondo et al., 2024, AGU abstract). We re-opened two fault-crossing trenches and newly excavated two additional fault-parallel trenches to reconstruct the cumulative offset based on buried channel deposits across the faults. We could precisely re-expose the original trench walls based on the same nails and strings used in 2014. The left-lateral displacement of the 2014 trench walls was measured at 1-2 meters with vertical displacement of a few tens cm. The exactly same faults mapped in 2014 trench re-activated and ruptured through the ground surface during the 2023 Mw 7.8 event, but no obvious faults were newly created during the 2023 event. The preliminary 14C dating results indicate that the last event before the 2023 earthquake occurred at least after 1054 AD. The average recurrence interval for the last 5 events including the 2023 event is 650-690 years. This interval is slightly longer but comparable with the most recent two historical earthquakes, previously reported as in 1513 AD and 1114 AD. Assuming the recurrence interval of 400 years and the elapsed time of 500 years since the 1513 earthquake, the occurrence probability in BPT model within the next 30 years could have been evaluated as ~35 % just before the

2023 earthquake. These paleoseismological evidences exhibit that high occurrence possibility before the 2023 event, though the evaluation of the total rupture length, rupture process and the final size of the multi-segment earthquake may have been room for consideration due to shortage of the dataset especially in space.

Acknowledgment: We deeply express our condolences to the victims due to the 2023 earthquakes. We thank to all collaborators in the joint research project 'Paleoseismological Study on the East Anatolian Fault System, Turkey' between Geological Survey of Japan/AIST and MTA. The re-excavation of the Kartal site was partly supported by JST J-RAPID program 'Verification study on long-term forecast of the 2023 Kahramanmaraş earthquake along the East Anatolian fault system'.

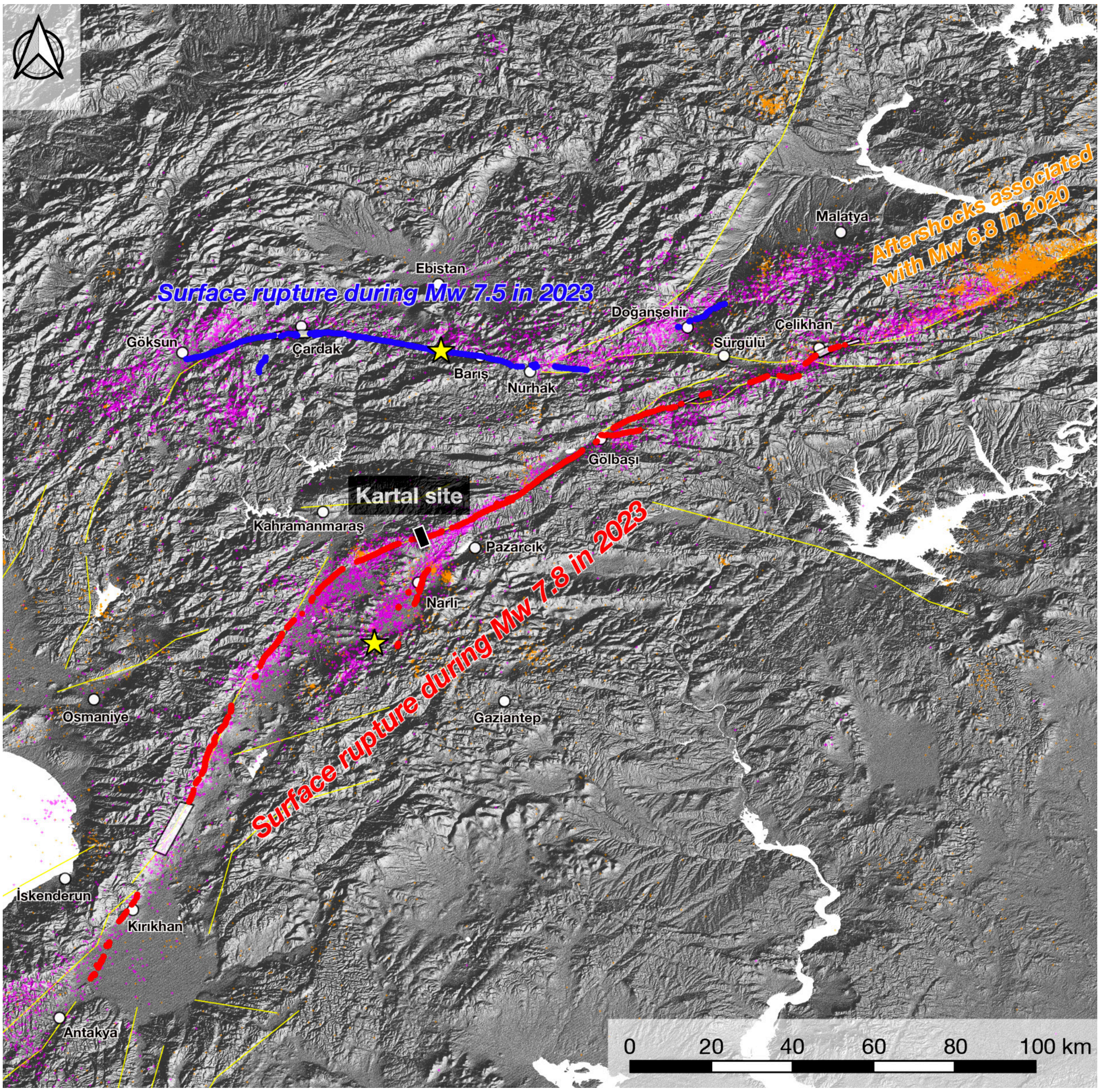

Figure 1 Surface ruptures during the Mw 7.8 and 7.5 earthquakes along the EAFS.
Modified from Kondo et al. (2023) on the GSJ web site.

Surface rupture signatures of historical earthquakes from Kumaon, Central Himalaya: Implications for Seismic Hazard Assessment

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In the last two decades paleoseismic studies in Himalaya (mostly along the frontal part) have revealed evidence of paleo-earthquake ruptures in the trenches excavated across the active faults, suggesting that the Main Frontal Thrust (MFT) ruptured during the historic past. About 52 paleoseismic trenches have been dug looking for the signatures of paleo-earthquakes and extend of surface ruptures associated with large or great earthquakes in Himalaya. These paleo-surface ruptures were corelated with the large magnitudes earthquakes those occurred during CE 1100, CE 1344/CE 1400, CE 1505, CE 1555, CE 1697, CE 1714, CE 1803, CE 1905, CE 1934, and CE 1950. It has been suggested that large magnitude earthquakes may have released a significant amount of accumulated strain in the Central and Northwest Himalaya during CE 1200-1344/1400. However, another thought process suggests that there are few earthquakes e.g., 1803, 1833, and 1905, that were not powerful enough to rupture the entire fault section right up to the frontal MFT.

Understanding the timing and rupture patterns of past earthquakes along with the tectonic convergence rates and the fault locking extents are crucial for enabling proper Seismic Hazard Assessment (SHA). However, significant contention exists in this regard in the Kumaon segment of Central Himalaya. General disagreement on the timing and along-arc rupture extent of the last great earthquake (CE 1344/1505 ??), which unlocked the entire fault segment releasing the accumulated strain and resetting the seismic clock, seriously impedes precise strain budgeting for the region. Furthermore, the debate intensifies for the 19th century (CE 1803) earthquake with two significant but diverging propositions, with one advocating it remained blind confined to the hinterland causing partial rupture on the Main Himalayan Thrust (MHT) while the other demonstrating complete rupture propagating south from the locking transition zone to the Main Frontal Thrust (MFT). The present study strives to resolve these issues by providing evidence from paleoseismic trench investigation and GPS-based crustal deformation modelling (CDM). Our trench uncovers signatures of three paleo-earthquakes: Event I between BCE 2298-725, uncorrelated with known historical events, Event II between CE 1347-1558, most likely the 1505 CE ($Mw \geq 8.0$), and the most recent event between CE 1734-1881, possibly the CE 1803 ($7.5 \geq Mw \leq 8.1$) earthquake. Therefore, suggesting that the CE 1505 was indeed the great event that reset the seismic cycle in Kumaon Himalaya, while the CE 1803 event caused displacement along MFT. The CDM supports that the CE 1803 being a surface (at MFT) rupturing earthquake by constraining the northernmost extent (~90-110 km from MFT) of its epicentral location

on the seismogenic locked MHT while accounting for the influence of the southward migration of the deformation front along the Piedmont Fault Zone (PFZ). Hence, we resolve and elucidate the contentious seismic catalogue of Kumaon Himalaya enabling proper future seismic hazard studies.

Spatial transition of rupture behavior along the Median Tectonic Line active fault zone in Shikoku, Japan

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[Introduction]

The Median Tectonic Line active fault zone (MTLAFZ) is one of the major active fault zones in Japan (Tsutsumi and Okada, 1996; Ikeda et al., 2009). This fault zone extends for 400 kilometers and is characterized as a trench-parallel dextral strike-slip fault. It accommodates the lateral slip movements of the Philippine Sea Plate, which is subducting obliquely beneath the Eurasian Plate (Fitch, 1972; Yeats et al., 1996).

The MTLAFZ has repeatedly caused multi-segment ruptures for a few million years. Previous excavation research has provided a lot of paleoseismological data to reveal the rupture behavior of the MTLAFZ. The paleoseismological data suggest a heterogeneous rupture behavior along the MTLAFZ. The average recurrence interval is assumed to be longer in the western Shikoku (about 3000 years; Tsutsumi and Okada, 1996; Headquarters for Earthquake Research Promotion (HERP), 2017) than in the central to eastern Shikoku (~ 1000 years; HERP, 2017; Goto, 2018). The average slip rate and amount of offsets at one seismic event are also similar to the trend as the average recurrence interval; lower in the western Shikoku than in the central to eastern Shikoku (Tsutsumi and Goto, 2006). This peculiar trend of paleoseismological data is one of the enigma or topic to clear the rupture behavior along the MTLAFZ.

Generally, earthquakes impart static stress changes to the surrounding crust. Consequently, a seismic event can trigger ruptures on the neighboring faults. As mentioned above, the MTLAFZ and Nankai-subduction zone are main components of forming the Nankai-forearc sliver. These geological components are inevitable sources of causing big earthquakes. Additionally, they are closely interacted with, and the activity of the MTLAFZ dominantly depends on the behavior of the Nankai-subduction zone.

In this study, we first calculate the change in Coulomb failure stress (ΔCFS) on the MTLAFZ at the event of the Nankai Earthquake. Then, we discuss the relationship between the stress perturbations on the MTLAFZ and the rupture behavior based on paleoseismological data.

[Method]

Stress perturbation on neighboring faults by large earthquakes is generally evaluated by the Coulomb failure criterion (e.g., King et al., 1994). We used Coulomb v. 3.3 stress-change software (Lin and Stein, 2004; Toda et al., 2005) to calculate Coulomb failure stress imparted by the Nankai Earthquake in an elastic half-space with a Young's modulus of 83.3 GPa.

For this calculation, we employed the fault model of the Nankai Earthquake as reported by Aida (1981). The static Coulomb failure stress change (ΔCFS) caused by the Nankai Earthquake is calculated as

$\Delta CFS = \Delta\tau + \mu'\Delta\sigma n.$

where $\Delta\tau$ is the shear-stress change on a given fault plane (positive in the direction of fault slip), $\Delta\sigma n$ is the fault-normal stress change (positive for unclamping), and μ' is the apparent coefficient of friction.

In this study, we set μ′ to 0.4 and the Poisson ratio to 0.25.

[Results and Discussion]

The results show the stress perturbation on the MTLAFZ caused by the Nankai Earthquake is positive for the central to eastern Shikoku, and negative or slightly positive for the western Shikoku. This variation of the stress perturbation is consistent with the transition of the rupture behavior of the MTLAFZ based on paleoseismological data. According to these data, the Nankai Earthquake has a significant impact on the MTLAFZ in the central to eastern Shikoku, but has little to no effect in the western Shikoku.

Consequently, the MTLAFZ in the western Shikoku needs other sources to promote preparation processes to cause ruptures. There are some candidates for the sources. The most plausible source can be the rupture of the MTLAFZ in the central to eastern Shikoku. The rupture of the MTLAFZ in the central to eastern Shikoku could affect the preparation processes of the faults in the western Shikoku. Additionally, the Hyuganada Earthquake might be another candidate for the sources. As the source fault of the Nankai Earthquake faces the central to eastern parts of Shikoku, and not the western parts of Shikoku, the position of the source fault of the Nankai Earthquake and the MTLAFZ could weaken the interaction with the MTLAFZ in the western Shikoku. On the other hand, as the plausible source fault of the Hyuganada Earthquake faces the MTLAFZ in the western Shikoku, the Hyuganada Earthquake could affect the preparation processes to cause ruptures of the MTLAFZ in the western Shikoku.

Offshore active fault survey on Futagawa Fault Zone, Kyushu, southwestern Japan

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During the 2016 Kumamoto earthquake sequence, two large earthquakes (Mw 6.2 on 2016/04/14 and Mw 7.0 on 2016/04/16, JST) and many aftershocks generated strong ground-motion and surface ruptures at Kyushu region, southwestern Japan. These earthquakes have occurred along the onshore part of Futagawa and Hinagu fault zones. Before the 2016 earthquakes, the Headquarters for Earthquake Research Promotion (HERP), Japan, evaluated these active fault zones based on existing studies (HERP, 2013). According to the evaluation, the Futagawa fault zone (FFZ) extends over 64 km long, which includes both of onshore and offshore active faults. The FFZ extends to offshore of Shimabara Bay, and the offshore part is called as "Uto-hanto Hokugan Section" and estimated to distribute 27 km long, at least. The offshore part of FFZ is firstly introduced by HERP (2013) mainly based on gravity anomaly and slight evidence of existing seismic profiles, however, precise fault lines nor past activity of the fault is not revealed yet. To reduce unknowns of seismic risk on active fault zones, we conducted offshore active fault survey on offshore part of FFZ as a part of an active fault research project commissioned by MEXT, Japan.

The offshore active faults are predicted to distribute on gravity anomaly zone, which lies along the northern coast Uto peninsula. We conducted ultra-high-resolution multi-channel seismic (MCS) reflection surveys in 2022 and 2023 to confirm existence and structure of the predicted offshore faults. We used a small MCS survey system with sparker sound source (energy output: 2000 J) and 24 or 72 channel receiver streamer cables (group interval: 2.5 m) to obtain high-resolution seismic reflection images. To improve the S/N ratio and quality of the images, we used twin GNSS navigation system and depth loggers to correct the depth of hydrophones on the streamer cables. We confirmed that there are offshore faults (mainly consist of north dipping normal faults). Thick Quaternary sediments are formed at north of the main fault, and are deformed and/or displaced by the faults. According to result of our MCS reflection surveys, the offshore part of FFZ extends to west toward the Shimabara Peninsula, and its length would be 11 km extended from the evaluation by HERP (2013). In 2024, we obtained a submarine drilling core in order to determine ages of sediments to elucidate past faulting events.

In Japan, offshore active fault surveys have been accelerated since 2000's. However, some offshore active faults and their potential risks are still not sufficiently understood. As we demonstrate in this study, recent MCS surveys can effectively confirm whether offshore active faults exist or not, especially when the Late Quaternary is distributed. The small MCS survey system we utilized in this

study successfully obtained high-resolution seismic images at vicinity of coastal line. In addition, offshore drilling survey may provide us sedimentary records to determine ages in the seismic sections, which are essential for investigation of past seismic events.

HERP (2013). Long-term evaluation of the Futagawa and Hinagu fault zones (2013 revision).

Nonplanar Fault Geometry Controls the Spatiotemporal Distributions of Slip and Uplift: Evidence from the Mw 7.5 2024 Noto Peninsula, Japan, Earthquake

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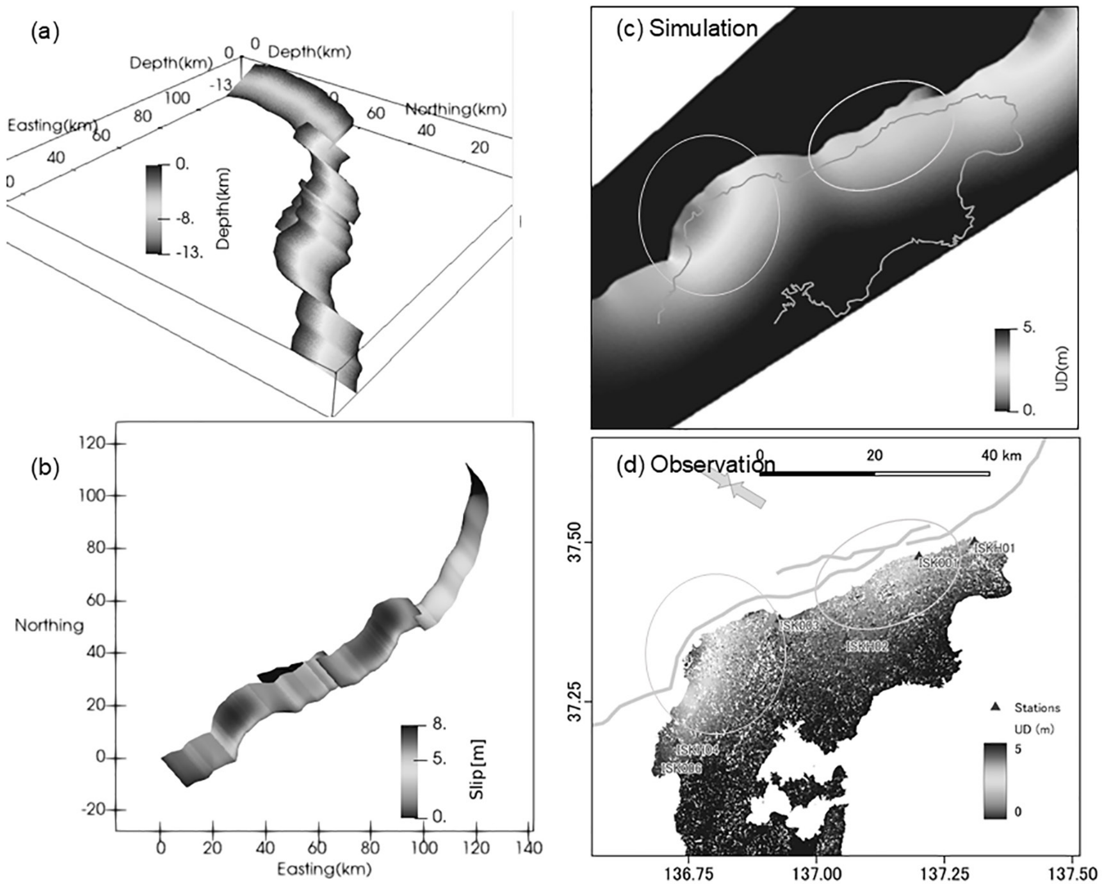
The 2024 Mw 7.5 Noto Peninsula Earthquake broke through a previously documented active fault system over 150 km in the northern central Japanese Island. This fault system is characterized by geometrical complexity. It is important to understand the physical mechanism underlying the multi-fault rupture. We conduct fully dynamic rupture simulations and identify that the 3D fault geometry (Figure 1a) controls the observed rupture process and heterogeneous spatiotemporal patterns of the fault slip (Figure 1b), seismic radiation and crustal deformation exhibiting about five meters of the maximum uplift. Aiming to examine the effect of the 3D fault geometry, we exclude the heterogeneity arising from the frictional properties. We also avoid frictional parameter tunings to fit the coseismic observations in order to test the forecastability of our simulations. The 3D nonplanar geometry model is built based on the previously documented surface fault traces, and we use the regional stress field determined by the stress tensor inversion (the maximum principal horizontal stress axis is shown as the arrow in Figure 1d.) As a result, the dynamic rupture simulation reasonably reproduces the observed characteristics of the heterogeneous deformation patterns (Figure 1c). We find the rupture is accelerated, and slip is increased where the fault is bent and optimally oriented to the regional stress orientations. Remarkably, the spatial distribution of surface displacement captured by the Synthetic Aperture Radar imageries is quantitatively reproduced, as characterized by two areas of large and small peaks of uplifts (Figure 1d). Our findings may contribute to increasing the forecastability of earthquake rupture scenarios.


(a)
Depth(km)
Easting(km)
Northing(km)
0
-13
100
80
60
40
20
0.
-8.
-13.
Depth(km)
(b)
Northing
120
100
80
60
40
20
0
-20
140
Easting(km)
8.
5.
0.
Slip[m]
(c) Simulation
5.
0.
UD(m)
(d) Observation
0
20
40 km
37.50
37.25
136.75
137.00
137.25
137.50
ISK001
ISKH01
ISK003
ISKH02
ISKH04
ISK006
Stations
UD (m)
5
0

Long-term forecast model for crustal earthquakes using geodetic data in Japan

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We developed a regional likelihood model for crustal earthquakes using geodetic strain-rate data in Japan. First, the smoothed strain-rate distributions were estimated from continuous Global Navigation Satellite System (GNSS) measurements in three regions into which mainland Japan is divided. Second, we removed the elastic strain rate attributed to interplate coupling on the subducting plate boundary, including the observed strain rate, under the assumption that it is not attributed to permanent loading on crustal faults. We then converted the geodetic strain rates to seismic moment rates and calculated the 30-year probability for $M \geq 6$ earthquakes in $0.2 \times 0.2°$ cells, using a truncated Gutenberg–Richter law and time-independent Poisson process. Likelihood models developed using different conversion equations, seismogenic thicknesses, and rigidities were validated using the epicenters and moment distribution of historical earthquakes in southwest Japan, where the long-term catalog of historical earthquakes is available. The average seismic moment rate of crustal earthquakes recorded during 1586–2020 was only 13–20% of the seismic moment rate converted from the geodetic data, which suggests that the observed geodetic strain rate includes considerable inelastic strain. Therefore, we introduced an empirical coefficient to calibrate the moment rate converted from geodetic data with the moment rate of the earthquakes. Several statistical scores and the Molchan diagram showed our models could predict real earthquakes better than the reference model, in which earthquakes occur uniformly in space. There were no significant differences in predictive skill between uniform and variable distributions for seismogenic thickness and rigidity. Finally, we combined three regional models into a single model using the same empirical coefficient. The preferred models suggested a high (≥1 %) 30-year probability in the Niigata–Kobe Tectonic Zone, Izu Peninsula, and central Kyushu.

Offshore seismogenic structure database of the Taiwan Earthquake Model (TEM)

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Taiwan is an active orogenic belt with many active structures and frequent earthquake activities. Currently, the Taiwan Earthquake Model (TEM) project has published 45 on-land structures, and such information has been used by many scholars and the government agencies for disaster assessment studies and preparation efforts. However, despite reports of active structures and many historical earthquakes offshore Taiwan, a comprehensive database of offshore seismogenic structures is still lacking.

In this study, we integrated results from previous geological and geophysical studies to determine the locations and subsurface geometry of offshore structures. We identified and mapped 54 offshore structures, and further estimated structural parameters such as possible earthquake magnitude, long-term slip rate, and earthquake recurrence interval. Using three empirical equations, all structures have the potential to produce earthquakes exceeding magnitude 6.5. The results show that the area with fast slipping (~10-20 mm/yr) structures is located in the hanging wall of the two subduction systems, whereas structures with lower slip rates (~0.1-2 mm/yr) are located in the post-collision zone off northeast Taiwan. Higher slip rates correspond to shorter earthquake recurrence intervals, such as the structures near the subduction zone with recurrence intervals of only a few hundred years. Due to the limitation of seismic data quality and topographic data resolution, these structural parameters still have large uncertainties and need to be refined afterwards. However, by establishing this offshore seismogenic structure database, we anticipate that the earthquake hazard assessments for Taiwan will be further improved.

Keywords: Seismogenic structures, Seismic hazard, Earthquake magnitude, Long-term slip rate, Earthquake recurrence interval

The first Amerindian earthquake victim, swallowed by a Boconó Fault open-crack, at the Aroa Range foothills, Yaracuy state, Venezuela

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The Boconó Fault (BF) is not only the most seismogenic onshore active fault of Venezuela in terms of both frequency and magnitude, but also the one that has deserved the largest research attention in terms of seismo-genesis since it counts with about a dozen of paleoseismic trench studies along its 6 segments (COLVEN and BOC-A through BOC-E; Audemard, 2014), extending for over 450 km from the Colombia border at the SW Táchira state boundary to the Caribbean coast of the Triste gulf in NE.
As a complement to the Yaritagua and Quigua trenches dug across segment BOC-E (the northernmost segment of all) in 2005 (Audemard, 2016), the latest paleoseismic study carried out in March 2015 across this segment counted with 3 new trench excavations, of which only the results of the Higuerón trench have been published so far (Pousse-Beltrán et al., 2018), as a negative consequence of a rocketing hyperinflation process suffered by Venezuelan scientific research, and country economy as well, since 2017. In that sense, the short- and long-San Ramón trenches are still pending for the highly expensive dating, except for a single very particular sample recently radiocarbon-dated. In fact, the Higuerón trench has identified 3 events, most likely the 1812 and 1736 AD historical earthquakes and an older one, thus confirming the 2005 Yaritagua trench (and Quigua trench too -?-) finding as to the association of the 1812 AD event with this BOC-E (San Felipe) segment.
The interpretation of seismic events in all five trenches (the 2 of 2005 and 3 of 2015) rests on the occurrence of organic-rich-filled open-cracks, poorly seconded by some colluvial wedges and upper-fault terminations. The two San Ramón trenches (Figure 1), some 25-30 m apart, were also dug across an uphill facing scarp, as at Higuerón. In the case of San Ramón Short (SRS), it was excavated at the north-facing foot of a SW-NE elongated pop-up (pressure ridge), while the San Ramón Long (SRL) cut a small north-exposed fault scarp affecting the recent alluvial deposits of a SE-draining river, in the NE prolongation of the NE tip of the pop-up (Figure 2).
The SRL trench walls expose a 2-m-thick rather well stratified pebbly sequence of variable pebble size, roundness and bed thickness of undoubted alluvial origin (Figure 3). The main BF trace appears in walls as two sub-parallel 30-to-50-cm-wide open cracks, which coincide with a slight surface sagging in the north, equally visible in the walls (Figure 3). The southern crack in the west wall, at mid-depth, after backhoe excavation, has displayed a rather well-preserved human skull (Figure 4). After careful hand excavation, the visible upper skull was accompanied of lower jaw containing all teeth, as well as other bones of the upper body, such as: cervical vertebrae, humerus, clavicle, shoulder blade and phalanges of a hand (Figure 5). The excavation was stopped at a perpendicular depth of 30-35 cm inside the wall, but we do believe the full skeleton was lying inside the crack, with head pointing NE.
Small fragments of bones were shipped for 14C dating to the LMC14 of CEA (Gif-sur-Yvette, France), yielding an age of 1780 ± 30 y BP (213-361 Cal AD; 95.4% probability). These human remains found in a filled open-crack produced during an earthquake, pre-dates the Spanish conquest by more than

eleven hundred years. There is no doubt that they must have belonged to an Amerindian; a young adult Indian based on the current condition of dentition (32 teeth -wisdom teeth present- and little cavities). This Amerindian fell inside the wide open-crack during the earthquake or very short after. Based on the crack stratigraphy, the victim is associated to the anti-penultimate earthquake (or older?).

Figure 1. Extract of GoogleEarth® image of relative location of the 3 trenches excavated in 2015.

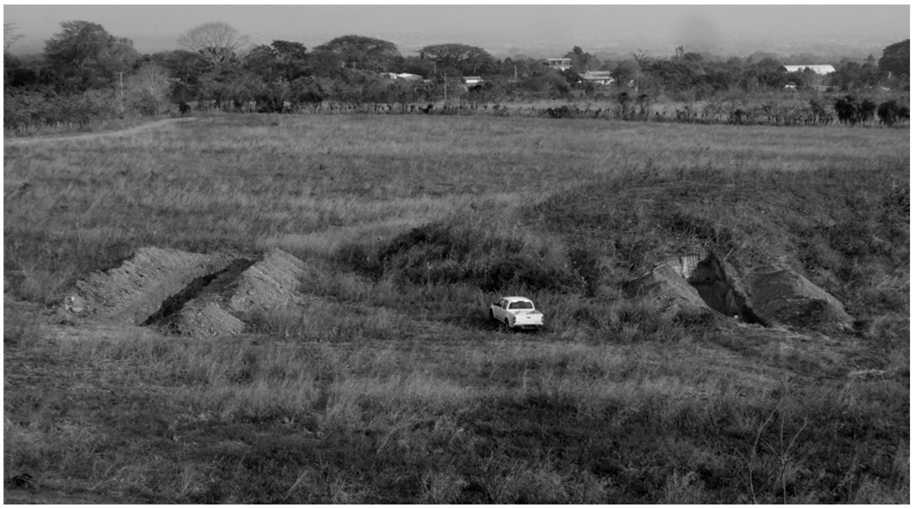

Figure 2. Bird-eye view of the San Ramón trench site.

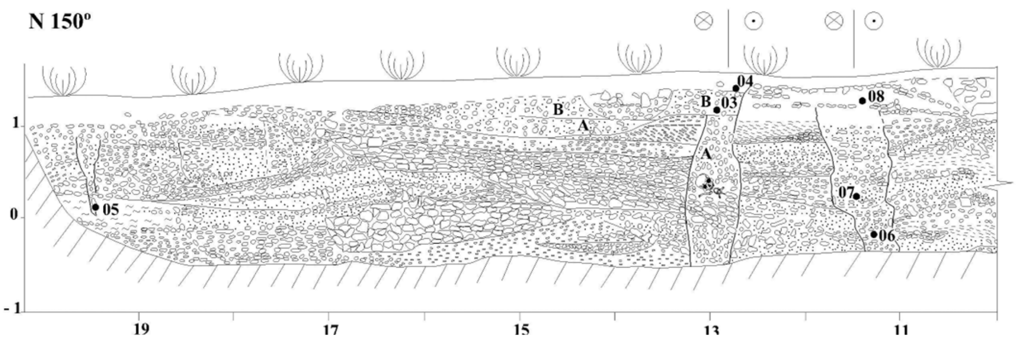

Figure 3. Southern portion of the trench log of the west wall of the San Ramón Long (SRL) trench, showing the cross-cutting relationship of the alluvial stratigraphy and BF open-cracks, in which was found the human remains (indicated by a skull and other bones).

Figure 4. Top of human skull as it was first spotted.

Figure 5. Frontal view of Amerindian skull.

Recent paleoseismic investigations by trenching of the major Algeciras Fault, Eastern Cordillera of Colombia

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The major Algeciras Fault (AF), belonging to the Colombian Algeciras Fault System (AFS), is part of a continent-scale dextral system, originally named as the Eastern Frontal Fault System -EFFS-, extending for 1900 km from Ecuador to Venezuela, which splits the North Andean Sliver from South America in a process of NNE-directed tectonic escape. To assess the seismogenic potential of AF, which is a highly potential seismic threat to Bogotá, the Geological Survey of Colombia (SGC) –after carefully mapping the AFS at its oblique crossing of the Eastern Cordillera, along the Garzón Massif northwestern border, on the basis of Quaternary landforms of tectonic activity-, has excavated 4 paleoseismic trenches across its trace in the Huila Department: two in the Algeciras pull-apart basin in 2016 (Lagunillas, Santa Elena) and two to NE of Garzón in 2021 (Potrerillos, Escuela Miraflores), 50 km apart to the southwest (Figure 1). Despite the evaluation of the Santa Elena trench is still pending, the Lagunillas trench, excavated across the basin shortcut strand, attests to seven Holocene Mw 7.0+ earthquakes, with an average recurrence of 1300-1400 years (Figure 2). In turn, both trenches at Miraflores were excavated across both strands of a restraining stepover. In fact, the Escuela Miraflores trench seems to assess the same AF Algeciras-Tres Esquinas segment as the Lagunillas one (Figure 3). This appears supported by that both trenches (Lagunillas and Escuela Miraflores) disclose the same latest February 09th, 1967 event. Besides, the AF slip rate deduced from the total deformation recorded at the Lagunillas site is about 0.7-0.8 mm/a, which is very similar to that of Miraflores (1.0 mm/a). In addition, the recurrence interval at Escuela Miraflores is of ~ 1500 years, from the last three events. Instead, the Potrerillos trench, opened across a fault trench, bounded by two normal-dextral faults 10 m apart, reveals that the SW-extending Garzón segment recurs much faster, at about 500-600 years, with latest events occurring roughly at 700, 1300 and 1800 AD. The trench-derived slip-rate of this segment is 4.0 ± 0.4 mm/a. Last, this segment seems responsible for the historical November 16th, 1827, Mw 7.1 earthquake, which would support the independent behaviour of both AF segments.

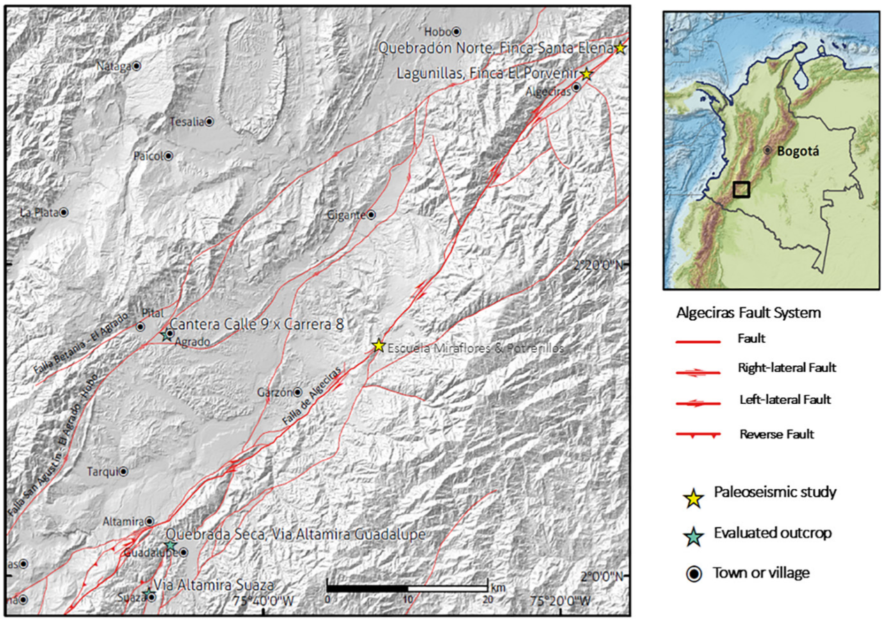

Figure 1. Trench studies location on the Algeciras Fault (AF), close to the towns of Garzón and Algeciras, in the Huila Department.

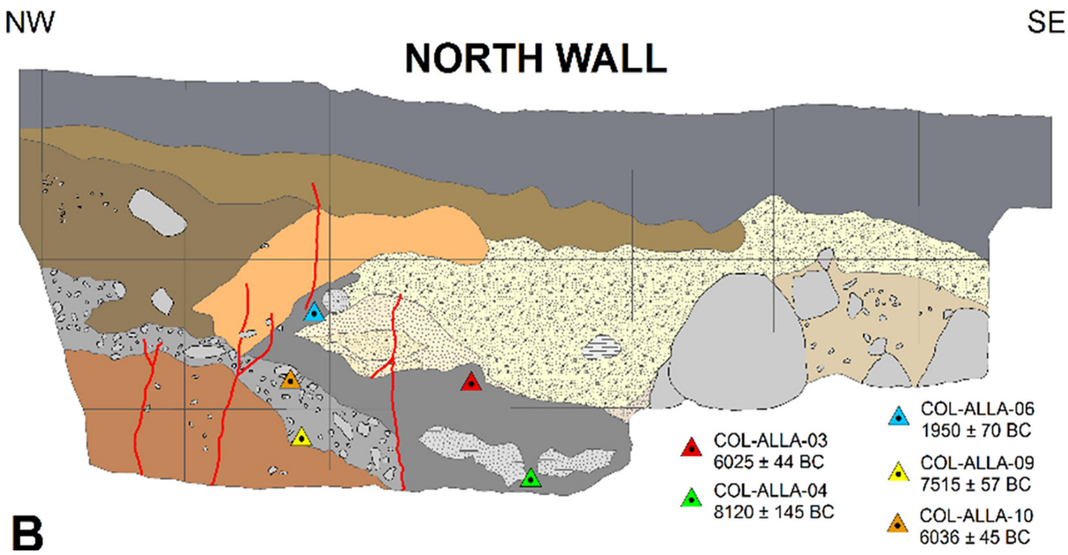

Figure 2. Trench log of the north wall of the Lagunillas trench, excavated across the AF shortcut in the Algeciras pull-apart basin, NE of the town of Algeciras.

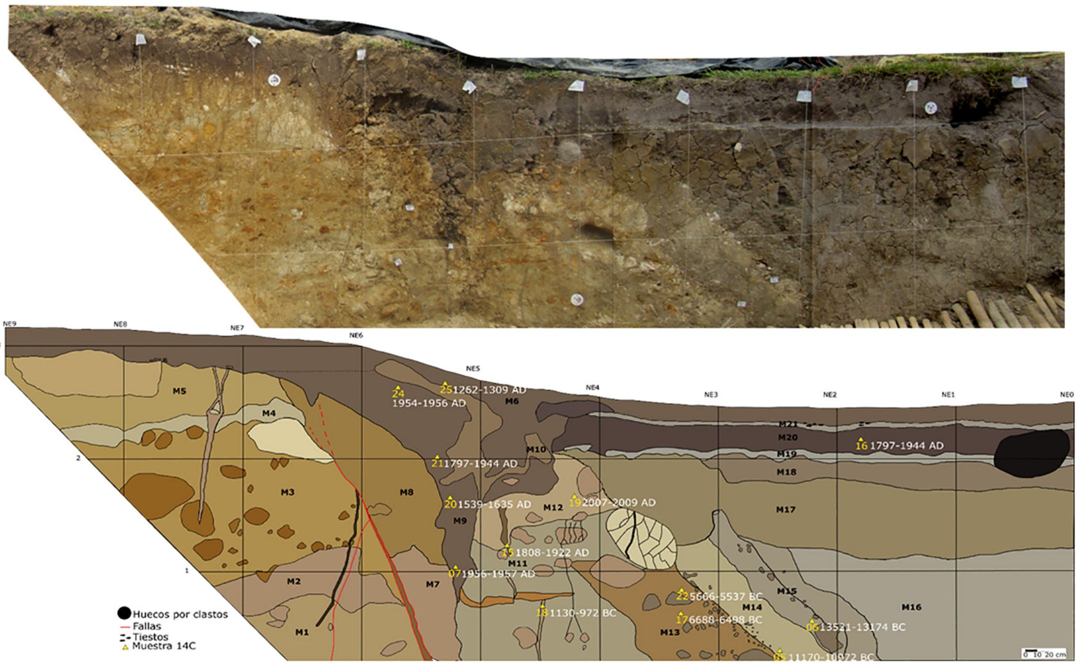

Figure 3. Trench log of the NE wall of the Escuela Miraflores trench, excavated across the AF, ENE of the Garzón and SW of the Zuluaga towns. Both trenches explore the slower (about a 1.0 mm/a) Tres Esquinas-Algeciras segment.

Mapping Active Tectonic Deformation Domains of SE Asia: Implications for Earthquake Hazards

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We present the first active tectonic deformation domain map of Southeast Asia, with a focus on Indonesia and Papua New Guinea. The map is derived from earthquake centroid moment tensor data, plotted on satellite imagery to identify the surface expressions of deformation domains related to active faulting. Seven distinct domains are delineated, each characterized by the dominance of a specific fault type. These domains are categorized as Dominantly Reverse/Thrust Faulting, Dominantly Normal Faulting, and others accordingly. A clear pattern of active tectonic deformation emerges across the region. Western Indonesia exhibits a dominance of strike-slip and thrust faulting, consistent with the oblique tectonic convergence between the Australian and Sunda plates. In contrast, eastern Indonesia is characterized by tectonic extension, with normal and strike-slip faulting being predominant. Borneo Island, in comparison, is tectonically passive, with significantly fewer earthquakes relative to the surrounding plate margins.

A prominent seismic shadow zone is observed in the Bird's Head region of eastern Indonesia. This feature is interpreted as a consequence of active faulting occurring along two major fault zones that border this region. In Papua New Guinea, the deformation domains are largely compressional in the frontal ranges but transition into normal and strike-slip faulting in the western regions. The eastern part of the island is dominated by strike-slip and normal faulting. The Woodlark and Solomon Sea areas exhibit extensive normal faulting, indicative of tectonic extension, while the Manus Basin is strikingly dominated by strike-slip faulting, with almost no normal faulting events observed.

The mapping of Active Tectonic Deformation Domains (ATDD) in Southeast Asia reveals significant variation in deformation patterns from the Andaman Sea to New Guinea. This variation reflects the differing manifestations of active tectonic convergence between the Australian and Sunda plates. Western Indonesia shows prominent tectonic compression, whereas eastern Indonesia is marked by tectonic extension. In Papua New Guinea, the deformation domains present a complex interplay: the eastern portion displays extension, the main body of the Bird's Head region shows a combination of compression and extension, and the eastern part predominantly exhibits extension.

These findings highlight that the active tectonic interactions between the Australian, Sunda, and Pacific plates are spatially variable, consistent with the broader dynamics of plate tectonic motion. Consequently, the revised version of the earthquake hazards is presented here.

Rupture History of the Himalayan Frontal Thrust near Bagmati River crossing in Central Nepal and the Future Scenario of Earthquake and Ground Motion Hazards for Kathmandu

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The 2015 Golkha earthquake raised concern about the future large earthquake in south of the 2015 source area. The Golkha earthquake ruptured 10 to 20 km deep portion of the plate boundary interface ~50 km away from the surface trace of the Himalayan Frontal Thrust (HFT). Therefore it is necessary to evaluate the earthquake potential of the shallowest part of the thrust in central Nepal.
After 2018 and 2019 paleoseismology works in Butwal area, in 2020 we excavated two trenches on the Himalayan front in east and in west of Bagmati river to examine the terminations of past events and to know the rupture history. At the Dumachaur Khola site 4 km east of Bagmati river, 3 or 4 events in 3500 years are excavated. The penultimate event here is dated around 3000 year B.P.. At the Gopalkoti-Dandatol site, 0.7 km west of Bagmati river, 3 events between 7th and 14th century C.E. are recognized. 1934 ruptures do not appear and 1255 (or 12th century) event is the last event in both trenches. The exposures were excellent with the master thrust fault through layered fine sedements containing many charcoal pieces, but the interpretation of the even time-series is difficult.
Findings from three trenches around Butwal and these two across Bamati River are as follows. (1) 1934 rupture did not reach Bagmati River in west. (2) In west of Butwal, the timing of the last surface rupture coincides with 1344 earthquake without any evidence of 1255 (or 13 century) and 1505 ruptures around Butwal. (3) The last event around Bagmati River crossing occured in 1255 or in 12th centrury. (4) The timing of the penultimate event in west of Bagmati River is about 1000 year B.P. while it is about 3000 year B.P. in east of Bagmati River. Though a lot of paleoseismological works has been carried out along the HFT in central Nepal and Central Seismic Gap, we still know little about penultimates event on most segments.
The results from these trench helped to define unruptured portion of the frontal thrust in past 770 years since 1255 CE. Summarizing past studies of rupture history, we set up a model that entire frontal thrust ruptured in 3 earthquakes of 1255 (eastern half), 1344 (eastern one third of western part) past, and 1505 (the rest of western part and India). 1934 earthauake ruptured central part of 1255 rupture in east of Bagmati and Sir Cora. 2015 earthquake ruptured the deeper part of the thrust in north between 1344 and 1934 rupture areas. The modeled unruptured portion of the frontal thrust is 220 km long and 64 wide reaching the surface along the Himalayan front between Butwal and Bardibas.
The scenario earthquake from this fault plane is Mw 8.1 and shakes Kathmandu basin much harder than in 2015 earthquake. In the central Kathmandu basin, MMI intensities are estimated to be VIII and XI with PGA 400 to 700 cm/s2. For the detail of the scenario,

Reference

Koketsu K., Miyake, H., Okumura, K., and Suzuki, H.: A future scenario earthquake and ground motion hazards for Kathmandu, Nepal. Earth, Planets and Space (2024) 76:75, https://doi.org/10.1186/s40623-024-02018-3.

Reexamination of historical coseismic uplifts of Murotsu Port, Kochi Prefecture and the time-predictable model for large earthquakes

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Shimazaki and Nakata (1980) (hereafter, SN1980) proposed a time-predictable recurrence model for large earthquakes (hereafter, time-predictable model) (Fig. 1 left) based on an analysis of Holocene coastal terraces and historical earthquake data in Murotsu Port in Kochi Prefecture, the southern part of the Boso Peninsula, and Kikaijima Island in the Satsunan Islands, which face the plate boundary of the Japanese archipelago. Murotsu Port has records of three major earthquake uplifts since the Edo period, and SN1980 estimated the amount of uplift by these historical earthquakes from existing historical records and existing research results (Fig. 1 right), but the later-mentioned inconvenience arose and reexamination was necessary.

Reexamination of the amount of uplift due to historical earthquakes at Murotsu Port

・Coseismic uplift due to the 1946 Showa earthquake

Sawamura (1953) adopted the amount of uplift of 115 cm at Tsuro, 2.8 km south of Murotsu, as the amount of uplift at Murotsu Port and SN1980 cited it. On the other hand, Sawamura (1953) determined the amount of uplift at Ukitsu Port, located across the Murotsu River from Murotsu Port, to be 110 cm. Since Ukitsu does not have a port, it is appropriate to consider the port to be Murotsu Port. For this reason, the amount of uplift at Murotsu Port due to the Showa earthquake is revised to 110 cm.

・Amount of uplift due to the Ansei earthquake of 1854

The『室津港手鏡』one of the Kubono family documents, states that the tide dropped by 4 shaku (shaku =30.3cm) after the Ansei earthquake, and this figure was taken as the amount of uplift at Murotsu in SN1980. The『八王子宮御当家記帳』(Tsuji, 1981) of Ukizu Hachioji shrine near Murotsu Port also states that the tide at Murotsu Port was reduced by four shaku. Since this is a local record of the observation of the tectonic uplift immediately after the earthquake, the amount of uplift in Murotsu Port due to the Ansei earthquake is taken as 4 shaku.

・Amount of uplift due to the Hoei earthquake of 1707

SN1980 estimated the amount of uplift to be 6 shaku based on Imamura (1930), but it cannot be ruled out the possibility that this value is influenced by mud dredging in Murotsu Port. Murotsu Port was a port directly controlled by the Tosa domain, and surveying officials carried out detailed depth measurements of the port down to sun (3.03cm). The『手鏡』one of the Kubono family documents records that the depth of the harbor entrance at low tide during spring tide before the Hoei earthquake was 6 shaku 5 sun. A historical document『宝永大変記』states that after the earthquake, large ships such as cargo ships were unable to enter the port, but small boats such as fishing boats were able to do so, and it can be surmised that the uplift of harbor entrance was only about 6 shaku 5 sun, so did not become land even at low tide during spring tide. Meanwhile, in the area around Kochi Castle, a document reported to the Edo shogunate by the Tosa domain 15 days after the earthquake contains a record stating that the amount of subsidence after the earthquake was just over 7 shaku. Just over 7 shaku is 7 shaku 1 to 2 sun, which amounts to 215 to 218 cm. The subsidence in Kochi due to the

Showa earthquake was 120 cm, and the uplift in Murotsu was 110 cm (Sawamura: 1953). Based on this relationship, the amount of uplift in Murotsu due to the Hoei earthquake can be estimated to be 197 to 200 cm (6 shaku 5 to 6 sun). Based on this result, the amount of uplift at Murotsu Port due to the Hoei earthquake is estimated to be 197cm (6 shaku 5 sun).

The next Nankai Trough earthquake will definitely occur in the not-very-far future. The result of reexamination fits the time predictable model more closely than SN1980 (Fig. 2), suggesting that the next Nankai Trough earthquake accompanied by significant coseismic uplift may be imminent.

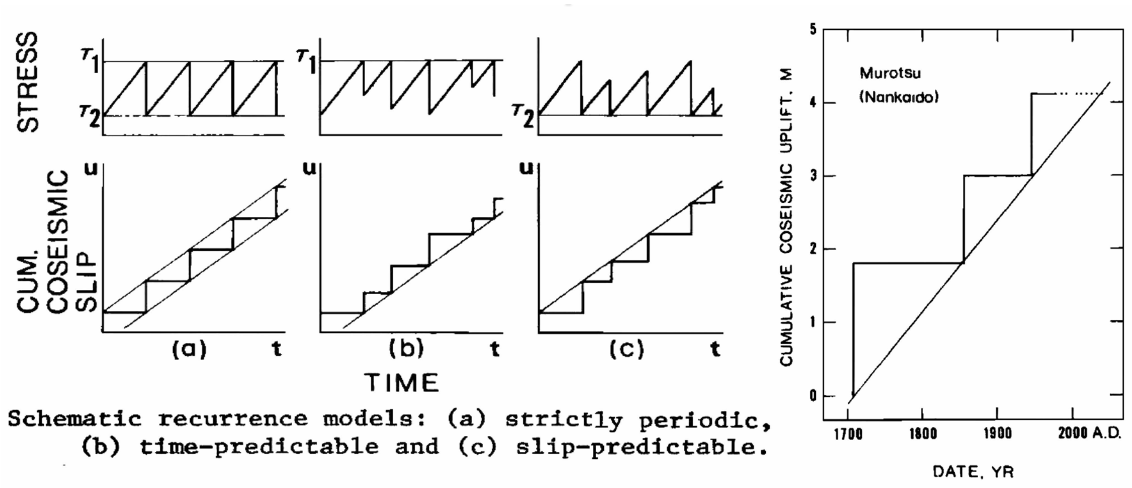

Fig. 1. Schematic recurrence models of large earthquakes (left) and cumulative coseismic uplift of Murotsu port against date (right) after SN1980.

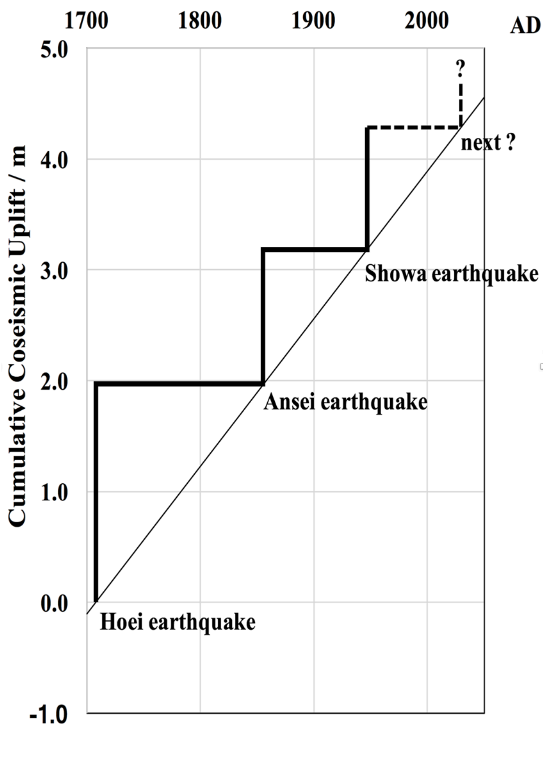

Fig. 2. Revised cumulative coseismic uplift of Murotsu port against date.

In memory of Professor Tokihiko Matsuda "Father of active fault studies in Japan"

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Professor Tokihiko Matsuda, "Father of active fault studies in Japan", passed away peacefully on October 17, 2023, surrounded by his family.

Professor Matsuda was born in Tokyo in 1931, and after completing his doctoral course at the University of Tokyo in 1959, he became an assistant professor at Faculty of Science, the University of Tokyo, an assistant professor at the Earthquake Research Institute in 1961, and an associate professor in 1965, before becoming a professor in 1982. After retiring from the University of Tokyo in 1992, he served as professor in the Faculty of Science at Kyushu University from 1992 to 95, in the Faculty of Science at Kumamoto University from 1995 to 97, and in the Faculty of Letters at Seinan Gakuin University from 1997 to 2002. After retirement from the university, he served as vice chief researcher at Earthquake Prediction Research Promotion Association about 20 years until a few years before he passed away.

He led active fault research in Japan throughout his life and he nurtured many active fault researchers through fieldwork and scientific discussions, making him a man who can be called the "father of active fault research in Japan."

Professor Matsuda was a noble, fair and kind person towards everyone. He was calm, humble and always had a smile on his face. However, as he spoke with emphasis about how leading geologists had repeatedly made disparaging remarks about active fault research when nuclear power plant construction was underway across the country, his strong belief and passion for active fault research was apparent.

Professor Matsuda's achievements are well known and need not be mentioned again, but he has pioneered the field of earthquake geology using geological and geomorphological methods to study earthquake faults and active faults, and has made numerous epoch-making contributions to the long-term prediction of earthquakes. Among these, it is worth noting that in 1975, he discovered the relationship between the magnitude of an earthquake, the length of an earthquake fault, and the amount of displacement based on major historical earthquake faults in Japan, and presented an empirical formula that would later be called the "Matsuda Formula." Later, in 1980, he also found from major historical earthquake faults in Japan a simple and beautiful relationship that the displacement of an earthquake fault in is approximately 1/10,000th of the fault length, and this relationship is also used in the country's fault evaluations.

"Active Faults of Japan," published in 1980 and considered the bible of active fault research in Japan, would not have been possible without his selfless contributions. After he was transferred to the Earthquake Research Institute, he often brought back 1:40,000-scale aerial photographs taken by the U.S. military and worked on interpreting them, creating maps of active faults for almost the entire country. However, he generously shared his findings, and worked hard to publish the above-mentioned publication that involved many researchers.

Professor Matsuda was also a man of field work. I had the good fortune to join him on several field surveys. In 1975, we studied the Senya fault, the source fault of the 1896 Rikuu earthquake. At the sites, he surveyed the fault scarp with an aerial photograph in one hand, a hand level and a tape measure (sometimes by pace measurement), and made the cross-section for measuring the amount of displacement. I learned the importance of a very modest, but important and careful survey manner from his method.

After turning 70, he joined the Society for Promotion of Earthquake Prediction Research, he enjoyed field work on the Iwaki earthquake fault in Fukushima Prefecture in 2011, the Boso Peninsula's Mimomo Coast, Enoshima and Oiso, and the Minobu fault, which was Professor Matsuda's ancient battlefield. His surveying style has not changed, and I can still picture him, energetic and ready to go into the bush with a surveying stick in hand. I also remember the late Professor Robert S. Yeats of Oregon State University, who met Professor Matsuda at international symposiums, praising Professor Matsuda as a real giant. The passing of Professor Matsuda is truly the loss of a giant star, but I am sure he would continue to watch over the future of active fault studies from the starry sky.

Professor Tokihiko Matsuda photographed during a field work on his 80th birthday in 2011. courtesy by Dr. T. Mizumoto

Developing probabilistic fault displacement hazard analysis frameworks for distal sites

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Fault displacement is a critical hazard to be considered in the seismic design of structures, along with strong ground motion. In recent years, standards and safety guidelines for probabilistic fault displacement hazard analysis (PFDHA) have been published, and social demand for probabilistic verification of fault displacement underneath critical facilities has increased. Here, the surface ruptures used by the PFDHA can be broadly classified into two types: principal fault, which is closely related to the earthquake source fault, and distributed fault, which appears as secondary or subsidiary fault due to the activities of the principal fault. Since critical facilities are generally built with separation from the principal fault, the practice of PFDHA for distributed faults away from the principal fault has become a necessity. However, there is no established method for evaluating PFDHA for sites away from the principal fault. As a fundamental problem, due to the limited practice of PFDHA worldwide, the practical issues with the current PFDHA have not been clarified. Therefore, we should practice PFDHA based on a model with higher accuracy, and then understand the current issues properly. From this point of view, the practice of the PFDHA using model of seismic source characteristics at the Ikata site based on guidelines for SSHAC Level 3 were reported by Nishizaka et al. (2024). In this study, we have referred to it as a precedent, and discussed the specific issues in the application of PFDHA at a practical level. The key issues are listed below. First, the existing fault displacement prediction equations (FDPEs) developed for the PFDHA are mainly based on fault displacement data obtained from field work in the vicinity of the principal fault. The development of new FDPEs with dramatically enriched distal surface rupture data, based on a combination of field surveys and remote sensing techniques, is a top priority for the wider application of PFDHA in the future. Second, the epistemic uncertainty in classifying surface ruptures into principal and distributed may lead to inaccurate occurrence rate of distal distributed ruptures. We should construct a new FDPE based on the dataset that solves this problem. Thirdly, existing FDPEs do not take into account any site effects specific to the assessment site. We should construct a new model to account for triggering displacements on existing active faults as an integral part of improving the accuracy of far-field fault displacement predictions. Since one possible mechanism for triggering distal surface ruptures is associated with sudden dynamic stress changes caused by strong ground motions, we should also consider probabilistic amplification factors at the assessment site.

Advancements in National Seismic Hazard Maps for Japan

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The 1995 Hyogoken-Nanbu Earthquake (M7.3), which struck at 5:46 AM on January 17, originated from an inland active fault at a depth of approximately 16 km near northern Awaji Island. The earthquake caused catastrophic damage, particularly in Kobe City and its surrounding areas, resulting in 6,434 fatalities, 3 missing persons, 43,792 injuries, and damage to 689,776 buildings, with total economic losses estimated at approximately 10 trillion yen. The severe structural damage caused by strong ground motion, exemplified by the appearance of the so-called heavy damage belt in the Kobe region, underscored significant challenges in earthquake disaster mitigation strategies of Japan. The Hyogoken-Nanbu Earthquake marked a critical turning point in approach to earthquake disaster management of Japan, significantly influencing research on strong ground motion prediction and seismic hazard assessment. Furthermore, it catalyzed the development of a nationwide strong motion observation network and the creation of the National Seismic Hazard Maps for Japan.

The National Seismic Hazard Maps for Japan have been created by the Earthquake Research Committee (ERC) of the Headquarters for Earthquake Research Promotion (HARP) in Japan with the aim of contributing to the reduction of earthquake disasters. These maps predict strong ground motion expected from potential earthquakes that may occur in Japan in the future. The National Seismic Hazard Maps for Japan consist of two types of maps: Probabilistic Seismic Hazard Maps that combine long-term probabilistic evaluations of earthquake occurrence and evaluation of strong motions predicted, and Seismic Hazard Maps for Specified Seismic Source Faults which are based on detailed strong motion evaluation for scenarios assumed for specific earthquakes. The ERC of HARP has been promoting the development of these seismic hazard maps. The first version of the National Seismic Hazard Maps for Japan was finalized and disseminated in March 2005. Subsequently, these maps have undergone annual updates through the assimilation of new evaluation data. In July 2009, after a decade of rigorous examination, the maps underwent significant enhancements, encompassing the incorporation of diverse datasets and the implementation of advanced cartographic methodologies. Additionally, the map grid resolution transitioned from approximately 1 km to approximately 250 m.

The Great East Japan Earthquake (M9.0) that occurred on March 11, 2011, was not factored into the earthquake activity models employed for the National Seismic Hazard Maps for Japan, resulting in various challenges. In light of these experiences, endeavors were undertaken to enhance seismic hazard assessment. The findings stemming from these efforts were disseminated by the ERC in 2012 and 2013 under the title “Considerations for Seismic Hazard Assessments.” Subsequently, an enhanced edition titled “National Seismic Hazard Maps for Japan - 2014 Edition” was published. Subsequent to this, updated hazard maps were conceived and released in 2016, 2017, 2018, and 2020, factoring in regional assessments of active fault zones and long-term evaluations of subduction zone earthquakes, as conducted by the ERC.

For earthquakes that occur at major active fault zones, in addition to probabilistic seismic hazard evaluation, certain scenarios are assumed and detailed strong motion evaluation is used to prepare Seismic Hazard Maps for Specified Seismic Source Faults. Seismic Hazard Maps for Specified Seismic Source Faults are prepared by using a seismic waveform synthesis method called the hybrid method for detailed strong motion evaluation. The hybrid method is a complicated waveform synthesis method consisting of multiple elemental technologies. Therefore, studies have been made to standardize the method and to develop such a method that could produce the same results for anyone. As a result, the ERC developed the strong ground motion prediction method ("Recipe") for earthquakes with specified source faults. The hybrid method based on the "Recipe" for strong ground motion prediction for earthquakes with identified source faults has been continually revised based on new insights. In 2016, revisions were made for long and large fault zones exceeding approximately 80 km in length. Additionally, new methods were added for intraslab earthquakes. Furthermore, in 2022, an interim report on the verification of the 2016 Kumamoto Earthquake was published to contribute to the ongoing improvement of the "Recipe".

The National Seismic Hazard Maps for Japan is positioned as the culmination of seismic hazard assessment, encompassing a vast amount of information, including data necessary for the creation of maps such as seismic activity models, seismic source fault models, and subsurface velocity structure models. As part of the hazard map utilization study, an engineering application committee (Chairman: Hiroyuki Kameda) to conduct investigations. The report of committee suggested that the National Seismic Hazard Maps for Japan should be regarded not only as the map itself as a final product but also as an information set that includes data related to the evaluation process of seismic activity models, seismic source models, and subsurface velocity structure models, which served as the prerequisites for its creation. The report proposed positioning it as the sharing platform of the seismic hazard information. To realize this proposal, we developed an open web system for seismic hazard maps, and started its operation in 2005 under the name "Japan Seismic Hazard Information Station (J-SHIS)", which was the name proposed in the report above.

Short-term variations in earthquake production in the southern San Andreas fault system due to lake level variations in Lake Cahuilla, Salton Trough, California: Implications for short-term slip rate variability

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Paleoseismic data collected over the past several decades among the major elements of the southern San Andreas fault (sSAF) system in the Salton Trough, southern California, show significant variability in earthquake production resulting from the presence or absence of the regional Lake Cahuilla. Modeling by Hill et al. (2023) demonstrate that ~100 m of water load effect the strength of the southern SAF due to variations in pore water pressure, and Rockwell et al. (2023) show that this effect also applies to the Imperial fault (IF) and elements of the southern San Jacinto fault. As M7 and larger earthquakes account for most of the moment release in the sSAF system, and as the majority of these larger earthquakes occurred during periods of high lake stand, this resulted in periods of higher moment release (clusters). Lake Cahuilla was dry for at least 1 ka between about 100 BCE and 950 CE during which the system equilibrated to lower pore pressure conditions. When lakes again filled the Salton Trough between about 950 and 1250 CE, earthquake production on the sSAF and IF increase by a factor of 2 to 3 suggesting that their slip rates also increased by this magnitude. These observations indicate that relatively small changes in water depth, such as lake level variations, seemingly innocuous differences in the water table, or the result of sea level rise from the late Pleistocene to the Holocene, can dramatically affect earthquake production on faults that are directly connect to a variable water system in a fluid saturated crust.

Why the Probability of Refining Regional Earthquake Probabilities in the San Francisco Bay Region is Low--and Will Remain That Way

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Since the first CA-wide time dependent earthquake probability forecasts for the primary faults of the San Andreas system in 1988 (WG88), these forecasts --for both individual sources and regions-- using a 30-year window of occurrence, have been effective in informing the public about earthquake hazards. They have been used by the government and private sector to prioritize planning, accelerate infrastructure retrofitting, and emphasize emergency response.

For the San Francisco Bay Region (SFBR), regional 30-year probabilities were issued in 1988, 1990 (post-Loma Prieta), 1999 (WG99), 2003 (WG02), 2007 (UCERF2), and 2014 (UCERF3). The mean probabilities and their uncertainties (not all calculated an uncertainty range) for these analyses are: 0.5(no ±), 0.67 (no ±), 0.7(±0.1), 0.62 (0.3-0.85), 0.63 (0.41-0.88), and 0.72 (0.52-0.94), respectively. Each estimate added, refined, and/or modified data, sources, and modeling approaches. UCERF3 even changed the type of probability it calculated, replacing nucleation probabilities of previous forecasts with physically different participation probabilities. For all the changes, and 26 years between the initial 1988 and most recent 2017 estimates, which model the time interval 2014-2043, the estimates have remained remarkably similar and are indistinguishable within the uncertainties.

The San Andreas and Hayward-Rodgers Creek faults are the two principal drivers of SFBR hazard, providing 26-34 mm/yr of the 37-45 mm/yr plate boundary slip through the region. Their slip rates, which control recurrence estimates used in the calculations, have remained essentially unchanged since 1999; the same is true for the other faults in the models. Without new and significantly different slip rates, or tightening of rate uncertainties, the SFBR probabilities in any future forecast won't change. Another major consideration is the short (30-year) probability window that might not capture large earthquakes in a region like the Bay Area where variation of moment release occurs over hundred-year-or-longer scales of time as evidenced by the paleo seismic cluster of large events in the late 1600s-late 1700s, the high rate of moderate events in the 1800s, and the ongoing post-1906 quiescence.

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