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SCIENCE OF SLOW-TO-FAST EARTHQUAKES

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INDEX

Fluid Migration and the 2024 Mw 7.5 Noto Peninsula Earthquake

A03 Slow-to-fast earthquakes through comparison across global subduction zones
Keisuke Yoshida (Graduate School of Science, Tohoku University)

On the northeastern Noto Peninsula, seismicity has increased since the end of 2020. During this period, microearthquakes migrated from deep to shallow depths via a complex network of faults, and large surface displacements have occurred that cannot solely be explained by seismic events. Based on these observations, previous studies have suggested that upward fluid migration from the deep crust has triggered this earthquake sequence. Given that a known active fault (i.e., the Suzu-oki segment) occurs at a shallower depth than the faults where the swarm activity has occurred, there is concern that a further large earthquake could be triggered. Indeed, the M 7.6 Noto Peninsula earthquake (hereafter referred to as the mainshock) occurred on January 1 2024.

To clarify the mechanisms that caused the mainshock, particularly its relationship to the preceding swarm, we estimated the precise locations of the mainshock, aftershocks, foreshocks (within a day of the mainshock), and earthquake swarm, and examined their spatiotemporal characteristics. Our results indicate that the mainshock rupture initiation and preceding foreshocks occurred on a fault that is deeper than the known active fault. We refer to this fault as the Suzu Blind Fault (SBF; Fig. 1). Microearthquakes have occurred and migrated on the SBF since ca. 2021, and the M 5.4 earthquake in June 2022 and M 6.5 earthquake in May 2023 occurred on the western and northern migration front of earthquakes, respectively. The 2024 mainshock also appears to have been initiated at the western front of the migration. Moreover, a complex network of faults that are a few kilometers in length exists immediately below the mainshock hypocenter, and the microearthquakes gradually approached the mainshock hypocenter from deeper levels via this network (Fig.1f–k). This suggests that fluids migrating through the SBF and via deeper small faults, along with the induced seismic and aseismic slip, triggered the mainshock.

The mainshock rupture on the SBF triggered ruptures on other active fault segments, including the Suzu-oki and Wajima-oki segments, leading to an earthquake with M 7.6. Large amounts of coseismic uplift occurred in this area approximately 8 km west of the rupture initiation area (Fig.2a), suggesting the mainshock caused large slip below this area. This area is located just east of the area uplifted during the 1729 M 6.6–6.9 earthquake, suggesting the mainshock ruptured the segment that remained unruptured during the 1729 event. The SBF appears to be connected to the Wajima-oki segment at depth, and the Wajima-oki segment is connected to the Suzu-oki segment at shallow depths. The large slip on the Wajima-oki segment may have contributed to the further rupture propagation.

It is widely accepted that crustal fluids and associated phenomena, including aseismic slip and deformation, can trigger small- to moderate-sized earthquakes. The Noto Peninsula earthquake clearly shows that crustal fluids can even trigger an earthquake as large as M 7.6. An important factor was that the active faults, which have repeatedly caused major earthquakes, were likely close to a critical state during the swarm activity. Detailed studies of the Noto Peninsula earthquake, which had abundant preceding seismicity, may provide detailed information on how a fault approaching a critical stage responds to external processes.

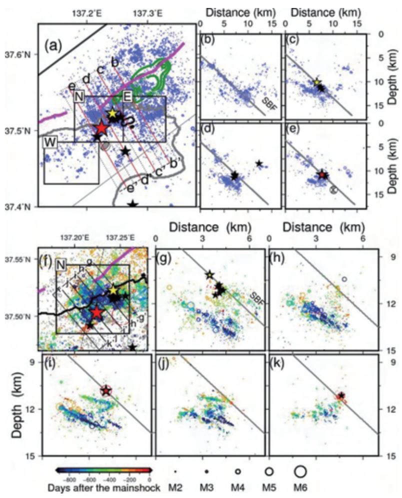

Figure1:
Hypocenter distribution near the mainshock (Yoshida et al., 2024; GRL). (a)–(e) Blue circles represent earthquakes in the 300 d before the mainshock. Red and yellow stars represent the hypocenters of the mainshock and immediate foreshock, respectively. Black stars indicate earthquakes within 1 d of the mainshock. The gray beach-ball represents the point source approximation of aseismic slip. (a) Map view. (b)–(e) Cross-sectional view. (f)–(k) Spatiotemporal earthquake distribution near the mainshock hypocenter. The color scale shows the time of occurrence for each earthquake. (f) Map view. (g)–(k) Cross-sectional view.

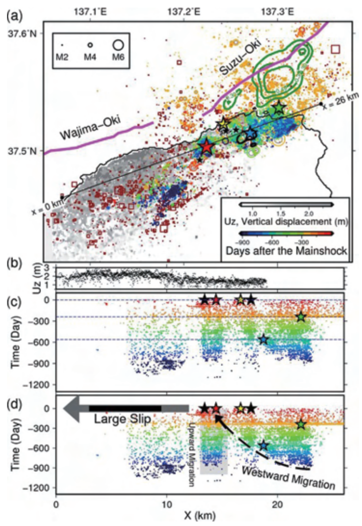

Figure2:
Earthquake migration on the Suzu Blind Fault (SBF) and quasi-vertical coseismic displacement (Yoshida et al., 2024; GRL). (a) Circles indicate the hypocenters of earthquakes on the SBF before the mainshock, the color of which represents the time of occurrence. Dark red squares represent aftershocks. The quasi-vertical coseismic displacement of the mainshock is shown by the background color. The green and black contour lines represent the coseismic slip distributions for the 2023 M 6.5 and 2022 M 5.4 events, respectively. The red, green, blue, yellow, and black stars represent the hypocenters of the mainshock, 2023 M 6.5 event, 2022 M 5.4 event, immediate foreshock of the M 7.6 event, and other foreshocks of the M 7.6 event (within 1 d), respectively. (b) Quasi-vertical coseismic displacement within 1 km of the x-axis. (c)–(d) Earthquake migration on the SBF in the direction of the x-axis (shown in a). The interpretation is given in (d).

Seismic Implications of Fault-Valve Behavior

B02 Data-driven discovery & monitoring of Slow-to-Fast earthquakes

Aitaro Kato (Earthquake Research Institute, The University of Tokyo)

An intense earthquake swarm has occurred for more than three years since November 2020 within a 20 × 20 km area beneath the northeastern tip of the Noto Peninsula, central Japan. The largest magnitude earthquake for each year from 2021 to 2023 increased from 5.1 to 5.4 and 6.5 by the end of 2023. On January 1 2024, a M 7.6 earthquake rupture nucleated within the swarm area and propagated bilaterally to the ENE and WSW along multiple faults. Globally, it is rare that a long-lasting earthquake swarm precedes such a large event. Seismic activity, crustal movement data, and resistivity analysis suggest that deep fluids were involved in the preceding earthquake swarm (e.g., Amezawa et al., 2022; Nakajima, 2022; Nishimura et al., 2023).

We relocated the earthquakes associated with the 2022 M 5.4 and 2023 M 6.5 ruptures by applying a double-difference relocation algorithm to differential travel-time data derived from a deep neural network-based picker model that can pick the compressional- (P-) and shear- (S-) wave arrival times from continuous waveform data (Zhu and Beroza, 2019). We then applied the matched filter technique (e.g., Kato et al., 2013) to the continuous waveform data (with the relocated earthquakes being template events) to enhance the relocated catalog. These results provide an excellent opportunity to explore the fault geometry and rupture area associated with these two large-magnitude events within the Noto Peninsula earthquake swarm, and possibly to infer fault-valve behavior from the expansion of the aftershock area to shallow depths immediately after the 2023 M 6.5 event (Kato 2024).

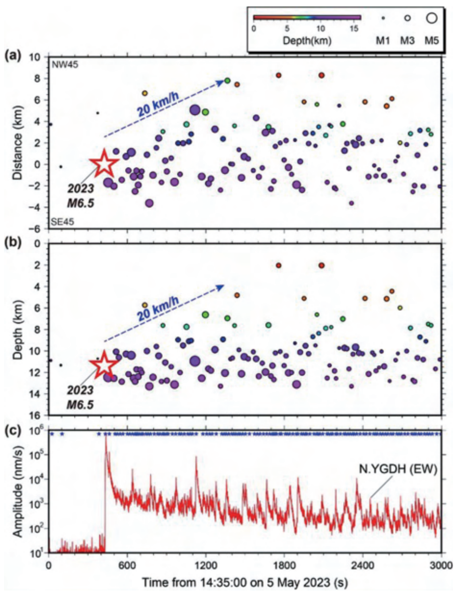

Figure 1: Space–time diagram of the immediate aftershocks following the 2023 M 6.5 rupture that were identified by the matched filter technique. Circles denote the aftershocks, which are scaled by earthquake magnitude and color-coded according to depth. The dashed blue line indicates a migration front that travelled at 20 km/h. (a) Horizontal distance along the N45˚W–S45˚E profile versus time. (b) Depth distributions.

Most of the aftershocks were aligned along a ~45˚SE-dipping plane. The M 6.5 event initially ruptured the same deep section of the fault zone that had been ruptured by the 2022 M 5.4 event, before propagating rapidly to shallow depths and offshore along the ruptured fault plane. The aftershock front migrated at a speed of ~20 km/h (Fig. 1), which is similar to or slightly slower than the speed of rapid tremor/low-frequency earthquake migration during slow-slip events along subduction zones (e.g., Kato and Nakagawa, 2020). This rapid upward migration of the immediate aftershocks might have been driven by the upwelling of crustal fluids along the intensely fractured and permeable fault zone via the mainshock dynamic rupture. This observation may be the first seismic evidence for the rapid migration of early aftershocks. The upward migration of the aftershock zone is consistent with fault-valve behavior (Sibson, 1992). The fault-valve model is defined by cyclical variations in fluid pressure within the fault zone, whereby they increase gradually during inter-seismic periods due to sealing/healing at the base of the brittle fault zone, resulting in overpressured fluids beneath the seismogenic zone. The increased permeability due to the coseismic generation of fractures in the fault damage zone leads to post-seismic fluid discharge along the fault from the overpressured parts of the crust. The fluid flow along the fault zone during the fluid discharge phase is recorded by the migration of the subsequent aftershocks (Fig. 2).

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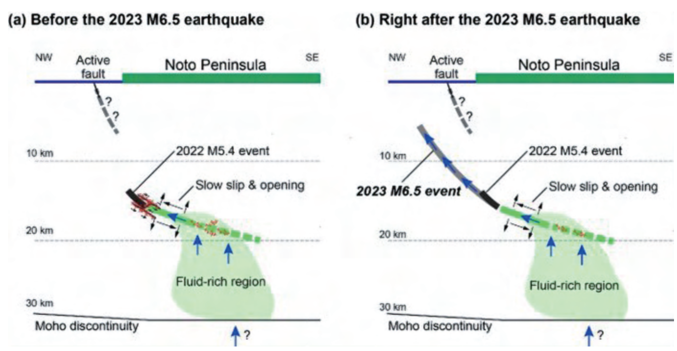

Figure 2: Schematic diagrams of the crustal processes during the protracted, intense earthquake swarm, based on Nishimura et al. (2023). Blue arrows represent possible fluid migration pathways. (a) Before and (b) after the 2023 M 6.5 event.

Fluid Migration Inferred from Gravity Observations on the Noto Peninsula

B01 Development of multi-scale observation techniques for monitoring Slow-to-Fast earthquakes

Yoshiyuki Tanaka (Graduate School of Science, The University of Tokyo)

Earthquake swarms have been active on the northeastern Noto Peninsula since the end of 2020, with major earthquakes of M6.5 and M 7.6 occurring in May 2023 and January 2024, respectively. Various observations have shown that crustal fluids are abundant near the epicenters of earthquake swarms. It has also been noted that fluids migrating from the subsurface were involved in the occurrence of these major earthquakes.

One method of quantitatively understanding fluid migration is crustal deformation monitoring by GNSS. Given that the deformation pattern at Earth's surface when fluid moves in the subsurface can be calculated from elasticity dislocation theory, it is possible to estimate the location and amount of fluid movement. However, this method can only determine the volumetric change and does not constrain whether the movement involved a cavity, water, or magma. To address this, we precisely observed changes in gravity over time using an absolute gravimeter that can make gravity measurements to the order of one billionth of 1 G. We conducted observations in the northeastern Noto Peninsula by combining data from an absolute gravimeter and a small relative gravimeter, which is less accurate but can make field measurements. The same technique has also been used to estimate magma movement in volcanic regions.

Our gravity observations revealed that significant gravity changes occurred before and after the May 2023 and January 2024 earthquakes. Figure 1 shows the results for the May 2023 earthquake. Fault slip occurred directly below station SZHK, where the absolute gravimeter was used. It is rare to acquire absolute gravity data above coseismic faults, and this is probably the first time that a large absolute gravity change exceeding 40 μGal has been detected for a M6 class earthquake. The observation is in good agreement with the height change observed by GNSS.

The change in gravity due to a height change can be theoretically estimated using the GNSS observation. By subtracting this from the gravity observation, we can estimate the contribution of underground mass transfer. A negative gravity anomaly of ~10 μGal was detected at station SZHK. Negative gravity anomalies occur when subsurface fluids approach the observation point and the crust is replaced by lighter material like water. A negative anomaly can be explained if the seismic shock increased the permeability of fractures around a fault and the fluid migrated through these fractures to the shallow part of the fault. The amount of fluid that can explain the observed gravity anomaly is ~10% of the amount that had accumulated on the deep fault prior to the May 2023 earthquake, as estimated from the GNSS data.

The January 2024 earthquake caused even larger negative gravity anomalies at stations SZHK and NTWT. Of note, near SZHK and NTWT, seismic wave velocity anomalies indicate the presence of fluid in shallow regions, as well as in the regions deeper than the coseismic fault near stations SZHK and NTWT. This process of fluid accumulation in the subsurface below the faults that migrates to shallower areas, in association with the occurrence of a major earthquake, may have been repeated in the past.

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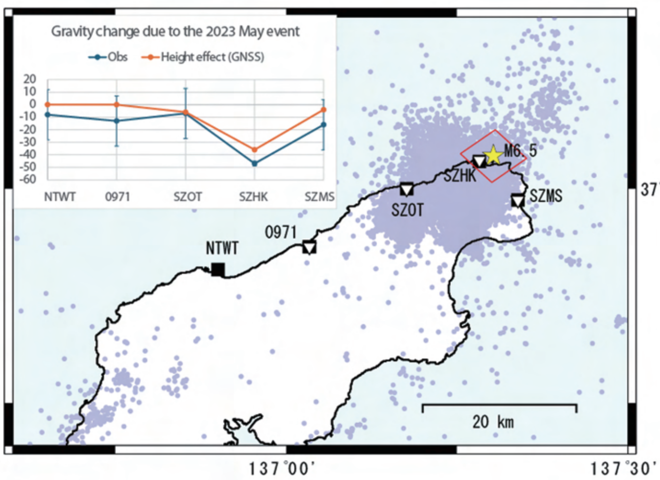

Figure 1: Gravity changes caused by the May 2023 earthquake. The gravity observations were conducted in March and May 2023. The graph shows the difference in the measurement results between March and May (unit = μGal). Station SZHK has a small error due to it being an absolute gravity measurement.

Submarine Fault Scarps Formed by the 2024 Noto Earthquake

A02 Anatomy of Slow-to-Fast seismogenic zones
Asuka Yamaguchi (Atmosphere and Ocean Research Institute, The University of Tokyo)

Fault movement on submarine active faults during earthquakes can cause coastal uplift or subsidence and generate tsunamis. The 2024 Noto earthquake resulted in coastal uplift of up to 4 m in the northern part of Noto Peninsula. Given that bathymetric data from the Japan Coast Guard indicated topographic variations had formed along an offshore active fault, we conducted a fault survey using an underwater drone (a small ROV) during an emergency research cruise of the R/V Hakuho Maru (KH-24-E1). As a result, we identified two steps on the seafloor off the northern coast of the Noto Peninsula (i.e., off the northwest coast of Cape Suzu and off the northwest coast of Wajima), which likely formed during the 2024 Noto earthquake.

The step found offshore to the northwest of Cape Suzu was discovered in bedrock (sandy sedimentary rocks) exposed on the seafloor and extended for >20 m NE–SW. This step is located south-east of a submarine active fault (the Suzu-oki segment), as inferred from a seismic reflection survey undertaken by the National Institute of Advanced Industrial Science and Technology (Inoue and Okamura, 2010). The height of the step appears to be < 1 m, with the northwest side being higher. In many places, the upper part of the step overhangs the lower part, and collapsed material can be observed along the step. The wall of the step and surfaces of the collapsed materials are not weathered, and there are no signs of algae or benthos, suggesting the step was formed within the last few months. These lines of evidence strongly suggest that the step is a submarine fault (i.e., a subsidiary transpressional back-thrust) created by reverse fault slip related to the 2024 Noto earthquake.

The step found offshore to the northwest of Wajima, as confirmed by a bathymetric survey, extends ENE–WSW and is located on the seafloor trace of a submarine active fault (the Saruyama-oki segment; Inoue and Okamura, 2010). The height of the step is < 1 m, with the north side being down relative to the south side. The surface of the step is covered with gravels and shell fragments, which disrupt the brownish cover typically found on the surrounding seafloor, indicative of recent disturbance. These characteristics suggest that the step is a flexural feature caused by fault displacement, and that the surface collapsed due to fault displacement related to the 2024 Noto earthquake.

Steps on the seafloor that may have been caused by the 2024 Noto earthquake were found in two of the three sites surveyed by the underwater drone. This suggests that fault slip during the earthquake reached the seafloor over a wide area along the northern coast of the Noto Peninsula.

Reference

Inoue, T. & Okamura, Y. (2010) 1:200,000 Marine geological map around the northern part of Noto Peninsula with explanatory notes.

Figure 1: Oblique view of a seafloor step (i.e., earthquake fault scarp) at the survey location offshore of the northwestern coast of Cape Suzu.

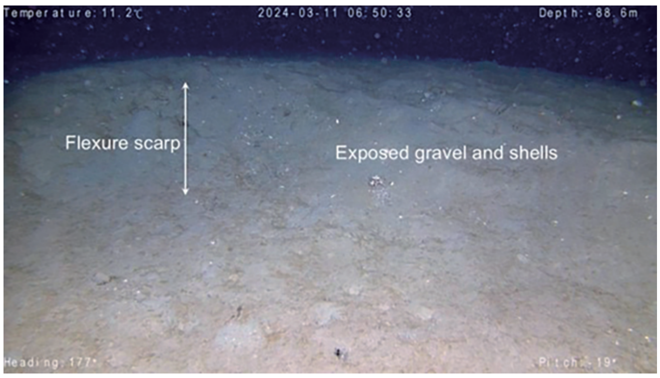

Figure 2: Frontal view of a seafloor step (i.e., flexural scarp) at the survey location offshore of the northwestern coast of Wajima. Gravels and shells are exposed on the surface of the step.

Rheology of Clay Minerals: Microscopic Insights from a Molecular Dynamics Study

A01 Physicochemical processes in slow-to-fast phenomena

Takahiro Hatano (Department of Earth and Space Science, The University of Osaka)

The 2011 Tohoku earthquake caused a large slip in the shallow part of the subduction zone, which led to a devastating tsunami. Subsequent drilling surveys have discovered clayey fault zones containing 60% – 80% smectite (Kameda et al., 2015). To determine the strength and slip stability of such clayey faults, the rheological properties of clay minerals have been investigated with laboratory experiments.

However, simulations based on simple physical models can complement the findings from laboratory experiments and drilling surveys, with an enhanced microscopic perspective of the clays. We investigated the microscopic origin of the rheology exhibited by clay minerals, using a molecular dynamics simulation. In general, clay mineral particles are known to have complex shapes and interactions. After some simplification, we adopted a disk-like ellipsoidal shape and the Gay–Berne potential for the interactions between the ellipsoidal particles. This effectively models the electrostatic effects of ions in water. The rheology and microstructure were then investigated by applying shear after an appropriate initial relaxation phase.

We first reached a steady state under a constant shear rate and then investigated the dependence of the shear stress τ on the shear rate γ and normal stress σ_n. Within the examined parameter range, the model exhibited a Herschel–Bulkley rheology, $\tau=\tau_0+A\gamma^\alpha$, where τ_0, A, and α are positive constants. As such, the frictional force in this model is velocity-enhancing (i.e., there is a positive dependence on the slip velocity). We also found that the constant τ_0, which is known as the dynamic yield stress, is approximately proportional to the normal stress. The exponent α ranges from 0 to 1 and decreases with increasing normal stress. This result also implies that slip may be more stable at a higher normal stress, because the degree of velocity strengthening at low velocities is enhanced for lower values of α.

Shear deformation was found to be uniform at higher strain rates, while the shear is localized (i.e., shear band formation) at lower strain rates. The shear band formation at low strain rates is consistent with the trend observed in experiments in previous studies. At intermediate slip velocities, the shear banding also depends on the normal stress and occurs at higher normal stress.

Without shear, the disk-like particles form a stacked structure due to an attractive interaction. The stacking structure developed in the initial state is broken by the shear, which requires a relatively large strain (~150%). Interestingly, this amount of strain required for the structural relaxation is broadly equivalent to that required for slip weakening from the initial state.

The stacked structure of the particles recovers after the shear ceases. The typical size of the stacked structure increases logarithmically with time (Fig. 1). This recovery process is more pronounced under a constant volume condition than a constant pressure condition, as more free volume is required for the structural recovery. Given that slip weakening corresponds to the breaking of the stacked structure, the time-dependent increase in the stacked structure is closely related to the frictional healing process of clay minerals. A “slide–hold–slide” test, in which the shear is applied again after a certain hold time, can directly link the structural recovery behavior to the frictional healing. However, such a test has not been possible to date due to technical difficulties. A more detailed investigation of this healing behavior should be undertaken in future studies.

Although particle simulations have led to the new findings described above, it should be noted that these are only microscopic observations. In particular, the formation of structures on a micrometer- to millimeter-scale, such as foliation or Riedel shears, as observed geologically and in the laboratory, can have a significant effect on the frictional strength of clayey faults. However, the formation of such structures cannot be examined with microscopic simulations. To take such effects into account and fully discuss the strength properties of clayey faults, we need to synthesize data from multiple approaches at different scales.

Details of the above results are summarized in Lin and Hatano (2024).

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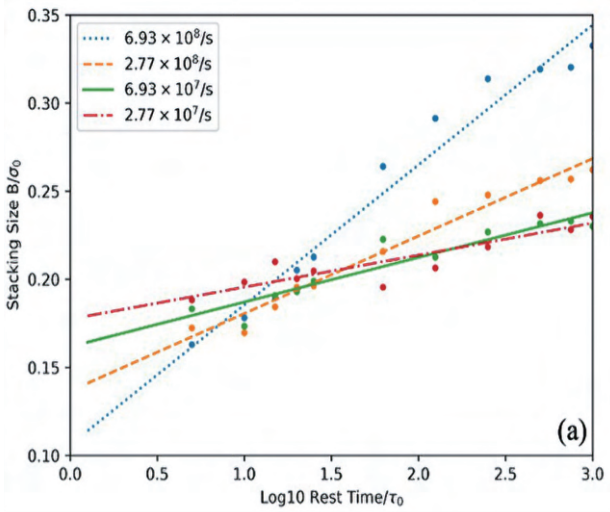


Figure 1: Logarithmic recovery of the stacked structure of clay particles with time. The different symbols correspond to the strain rate during shearing. Only the system that was sheared the fastest recovers quickly, and the recovery behaviors of the other systems are similar in all cases.

Advanced Exploration, Monitoring, and Modeling Techniques for Revealing the Spatiotemporal Characteristics of Earthquakes

A02 Anatomy of Slow-to-Fast seismogenic zones

Takeshi Tsuji (Graduate School of Engineering, The University of Tokyo)

We applied engineering approaches to seismology to characterize the location and timing of earthquakes. Here, we briefly introduce examples of our studies that have used advanced exploration techniques to image fault zones in the Nankai Trough, to monitor the dynamic behavior of the subduction zone and model fault evolution.

In oil and gas exploration, seismic data analysis has advanced significantly, allowing not only imaging of geological structures, such as faults, but also accurate estimation of seismic velocities to assess the gas distribution and pore pressure. Figure 1a shows the high-resolution P-wave velocity distribution in the Kumano Basin of the Nankai Trough. Areas with lower seismic velocities are considered to be regions with high concentrations of methane gas. In addition, a large fault branching from the plate boundary fault is located beneath the gas reservoir, indicating the gas has migrated upward along the fault. Similar analyses have revealed that the area beneath the plate boundary fault has a high pore pressure (Fig. 1b). Mapping of the thickness of this region of high pore pressure has shown that slow earthquakes occur frequently in areas where the thickness of this region is substantial and also that earthquakes are concentrated in places where the thickness changes significantly (Fig. 1c). This suggests that slow earthquakes are affected by the structures identified by geophysical surveys, such as zones of high pore pressure.

In addition to the techniques used for visualizing and characterizing the subsurface, recent advances in sensor technology, such as fiber optic sensing, and improvements in computational approaches have enhanced efforts to monitor changes in the sediment and crust. Figure 1d shows the results of monitoring changes in the seismic velocity within the Nankai accretionary prism using microtremor data recorded by DONET. The seismic velocity decreases when an earthquake occurs, which is thought to be partly due to increased pore pressure within the sediments. Another interesting observation is that, excluding events such as earthquakes, there is a long-term increase in seismic velocity (black arrows in Fig. 1d). This is thought to reflect strain accumulation associated with subduction, suggesting that precise monitoring could potentially reveal the build-up and release of strain around the plate interface. Currently, students are researching this topic, and intriguing results, such as the relationship with slow earthquakes, have been obtained.

As the amount of information obtained by monitoring technologies increases, the methods for interpreting that information become important. To address this, we have been developing a technique called “digital rock physics”, which involves the digitization of rocks and modeling of fluid behavior and elastic properties within the rocks. This allows us to interpret changes in fluid behavior based on variations in seismic velocity. Initially, this technique was developed for projects such as carbon capture and storage (CCS), but it is also applicable to fault systems and could contribute to seismology. Recently, research has advanced to include molecular-scale numerical simulations to calculate fluid interfaces and mineralization reactions, and then upscaling of these results to rock-scale digital models (Fig. 1e). This enables the modeling of secondary mineral formation within fractures and associated changes in hydrological and elastic properties, which allows quantitative interpretation of the monitoring data. We refer to this approach as digital rock physics and chemistry.

While we have demonstrated that engineering approaches can be applied to seismology, geoscientific knowledge is also required in engineering fields. For example, CCS and geothermal development face the challenge of induced seismicity, where insights from seismologists are key in addressing these problems. We intend to continue investigating earthquakes and other phenomena, transcending the boundaries between engineering and science.

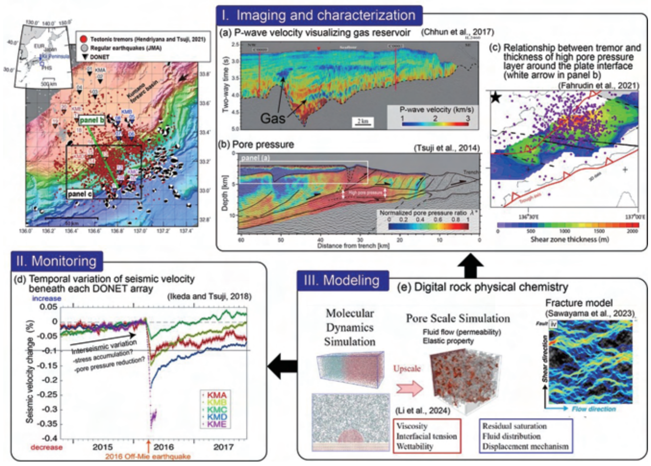
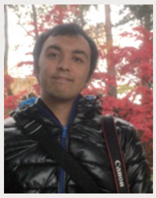


Figure 1: Research on the imaging, monitoring, and modeling used to characterize the location and timing of earthquakes in the Nankai Trough. (a) P-wave velocity in the Kumano Basin. The location is shown by the white rectangle in (b). (b) Distribution of pore pressure. The location is shown by the green line on the map. (c) Relationship between slow earthquakes and the thickness of the layer of high pore pressure. (d) Temporal changes in seismic velocity based on monitoring beneath the DONET network. (e) Quantitative interpretation of imaging and monitoring data using digital rock physics and chemistry.

Are Clusters of Quartz Veins in Subduction-Related Shear Zones the Geological Fingerprints of Slow Earthquakes?



A03 Slow-to-fast earthquakes through comparison across global subduction zones

Suguru Yabe (Geological Survey of Japan, AIST)
Kohtaro Ujiie (Graduate School of Science and Technology, University of Tsukuba)

Large amounts of high-pressure pore fluid are present in the source regions of slow earthquakes, based on seismological studies of the subsurface structure (e.g., Shelly et al., 2006). High-temperature and high-pressure fluids can dissolve silica and, when slow earthquakes occur, the permeability of a fault increases, causing a decrease in pore fluid pressure. This process may result in the precipitation of quartz veins (Audet and Bürgmann, 2014). In fact, geological studies have documented dense clusters of quartz veins in ancient, deep, subduction-related shear zones. Based on the characteristics of shear deformation at high fluid pressures in quartz veins, such veins have been suggested to be possible fingerprints of slow earthquakes (e.g., Ujiie et al., 2018). In this study, we examined whether the seismic waves produced by present-day slow earthquakes could be explained by clusters of quartz veins.

Outcrop observations show that clusters of quartz veins are tens to hundreds of meters thick (Fig. 1), and are continuous for several kilometers along strike (Ujiie et al., 2024). These clusters contain numerous quartz veins of ~1 m in size. The displacement of the shear veins is quite small (~0.1 mm). We modeled the radiation of seismic waves by the successive rupture of these small quartz veins by combining two models: one for the seismic waves radiated from the individual ruptures and the other for the diffuse propagation of crack ruptures, which is characteristic of a slow earthquake. Our results show that the magnitude of the signals emitted from these quartz vein clusters is consistent with the observed seismic signals, supporting the hypothesis that quartz vein clusters may be a geological fingerprint of slow earthquakes.

The quartz vein clusters investigated in this study are located from the down-dip limit of the seismogenic zone to above the mantle wedge in a subduction zone. However, slow earthquakes occur not only in deep subduction zones, but also in their shallower parts, as well as in transform faults, collisional zones, and inland faults. Given that slow earthquakes in various tectonic settings in subduction zones exhibit similar characteristics (Takemura et al., 2024), their mechanisms should be independent of the specific tectonic setting. The key component of this model is not the presence of quartz vein clusters, but the existence and scale of a network of small cracks. We suggest this model is broadly applicable to slow earthquakes. Networks of mineral veins are also found in shear zones at depths even greater than the mantle wedge corner in subduction zones (Okamoto et al., 2021). In shallower parts of subduction zones, aquifers (i.e., networks of voids) of a similar scale to quartz vein clusters are inferred to exist (Hirose et al., 2021). These observations suggest that a network of small cracks corresponding to slow earthquakes may be ubiquitous within shear zones in various tectonic settings.

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Figure 1: Photograph of quartz veins in a subduction-related shear zone.

A New Surface Platform for Seafloor Geodesy

B01 Development of multi-scale observation techniques for monitoring Slow-to-Fast earthquakes
Yusuke Yokota (Institute of Industrial Science, The University of Tokyo)

In the 1980s, F. Spiess at the Scripps Institution of Oceanography proposed several seafloor geodetic techniques (e.g., Spiess, 1985). One of these techniques, called Global Navigation Satellite System-acoustic ranging (GNSS-A), has been actively studied since the 1990s (Fig. 1), and it is now possible to observe crustal deformation on the seafloor with centimeter accuracy. Over the past decade, this observational technique has become indispensable for understanding slow and fast earthquakes beneath the seafloor at plate boundaries, such as detecting crustal deformation caused by earthquakes, post-seismic deformation due to the Tohoku-oki earthquake, and the distribution of slip deficit and shallow slow slip events in the Nankai Trough (Fujita et al., 2006; Sato et al., 2011; Watanabe et al., 2014; Yokota et al., 2016; Tomita et al., 2017; Yokota & Ishikawa, 2020; Brooks et al., 2023). In recent years, equipment development has progressed through tank experiments, electrical circuit investigations, and signal analysis, making it possible to detect not only horizontal but also long-term vertical movements of <1 cm/yr (Yokota et al., 2024).

The biggest obstacles to these observations are aspects of marine engineering. During such observations, the surface platform constantly measures its own position using high-rate GNSS and, at the same time, undertakes acoustic ranging with an acoustic station previously installed on the seafloor. By combining these data, the precise seafloor position can be obtained. Traditionally, ships have been used for this surface platform, but due to cost and other constraints, it has only been possible to achieve an observational frequency of <3 months. Moored and self-propelled buoys have also been used, but it is difficult to undertake observations in strong-current and high-latitude areas and there are difficulties with emergency responses. As such, there are still many developments that need to be achieved for the surface platform.

We are conducting research on observational technology using sea-landing Unmanned Aerial Vehicles (UAVs), which are one option for a next-generation surface platform (Yokota et al., 2023). UAVs have the ability to move on their own on the sea surface and can be treated as self-propelled buoys that can fly, which can solve the aforementioned marine engineering problems. However, because they fly, there are weight and space constraints, and there are further developments required, such as the size of the equipment, its placement, and temperature countermeasures. In addition, because these aircraft have not been used in the field of marine acoustics, there are marine acoustic research aspects to be developed, such as a multipath sea-surface platform and sonar dome. We have addressed many of these challenges using water tank and sea area tests, and it has been confirmed that the observational accuracy, which was only 1 m in the first year of the experiment, has reached the centimeter-scale, similar to that of a ship (Fig. 2).

This observational technology is not yet complete and there are still engineering issues that need to be solved. This type of automated sea surface observational technology can potentially be applied to numerous marine observational engineering projects, such as ocean monitoring. This research is applicable to not only solid Earth science, but also interdisciplinary engineering projects.

In recent years, research into ocean observation platforms that will be the next generation of ships has finally begun to progress, not only with UAVs, but also with the development of the Wave Glider and new self-propelled buoys. Seafloor geodesy aims to undertake more accurate monitoring of the sub-seafloor by combining each of these unique technologies.

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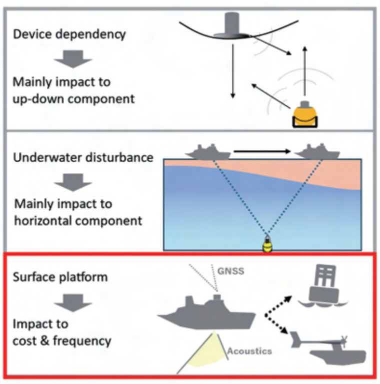

Figure 1: Research themes of GNSS-A observations.

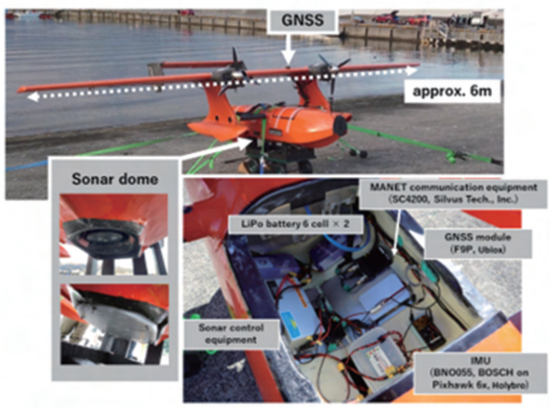

Figure 2: A UAV for conducting GNSS-A observations.

Automatic Classification of Tectonic Tremors from Continuous Seismic Waveform Records with an Unsupervised Machine Learning Technique

B02 Anatomy of Slow-to-Fast seismogenic zones

Yuki Kodera (Meteorological Research Institute, Japan Meteorological Agency)

Continuous seismic waveforms recorded by a seismometer include various signals such as earthquakes, human activities, and instrumental noise. If an automatic classification of continuous records is possible, it would be possible to understand geophysical phenomena around a target seismometer and monitor the instrumental conditions of a seismometer used in a real-time system. We have been developing an unsupervised automatic classification algorithm for continuous seismic records that is applicable to various seismometers deployed in different observational environments. The unsupervised approach has the advantage of the algorithm not requiring prior knowledge (e.g., a template) of what types of signals are included in the record. Here, we describe the application of the proposed algorithm to the classification of tectonic tremors.

The proposed algorithm is divided into three parts: (1) feature extraction, (2) clustering in the frequency domain, and (3) clustering in the time domain (Fig. 1). In the feature extraction process, running spectra are used as features, calculated with a 4-s time window every 0.1 s. The running spectra are then converted into 10-dimensional vectors through a filter bank with 10 separate frequency bands. In the clustering in the frequency domain, the dataset is clustered by selecting 2000 representative points (RPs) and assigning each data point to the nearest RP. We determine the RPs by random sampling, after dividing the dataset into several groups based on distances between data points to address the imbalanced data problem (i.e., the amount of stationary noise signal data is the largest). In the clustering in the time domain, the RPs are converted by kernel principal component analysis (kPCA; the kernel is a transition matrix generated assuming a Markov chain) and clustered using the Ward hierarchical clustering algorithm in the space mapped by the kPCA. Finally, the classification results are obtained by cutting the dendrogram at 25% of its maximum height.

We tested the proposed algorithm by applying it to one-week-long continuous waveforms recorded at five temporary ocean-bottom seismometers deployed to observe aftershocks of the 2004 M 7.4 off the Kii Peninsula earthquake (Yamazaki et al., 2008). The record includes many shallow tectonic tremors in addition to aftershocks (Fig. 2; Tamaribuchi et al., 2019). The classification was conducted individually for each station and, therefore, five independent classification results were obtained. For every station, the tectonic tremors were assigned for unique class(es) that were different from those of background noise and fast earthquakes, indicating the proposed algorithm successfully detected tectonic tremors based on the unsupervised approach. We also evaluated the detection rate of tremors by comparison with the tremor catalog of Tamaribuchi et al. (2019), which was provided by manual inspection of the record. The detection rate was 87% for the entire record, which suggests the proposed algorithm could detect tremors in the catalog at a high detection rate, although the algorithm did not use specific knowledge of tectonic tremors as a template. However, in some cases, tremors and coda waves of fast earthquakes were not completely separated because of their similar frequency characteristics. In future, we will improve the proposed algorithm in several ways, such as changing the selection of features fed into the hierarchical clustering process.

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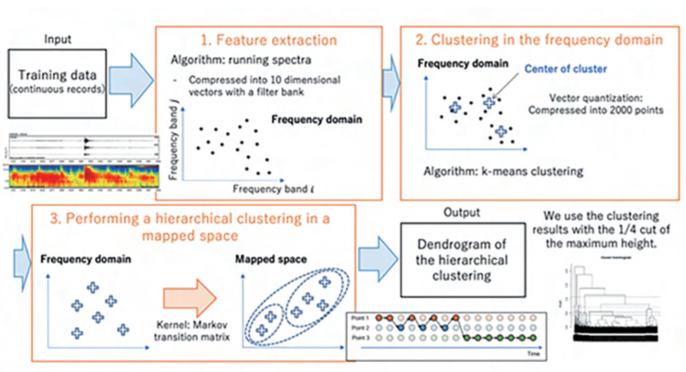

Figure 1: Overview of the proposed algorithm. The algorithm is divided into three steps: (1) feature extraction, (2) clustering in the frequency domain, and (3) clustering in the time domain.

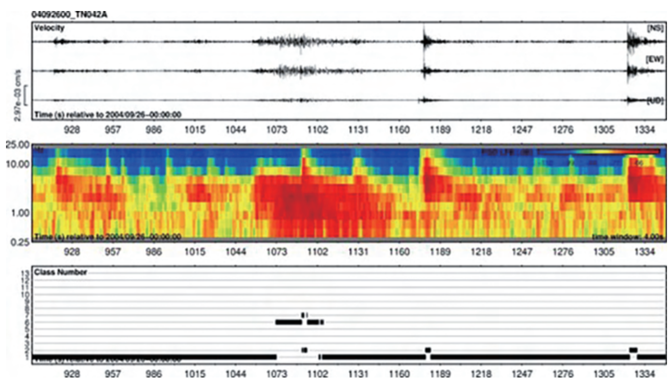

Figure 2: Example of classification results for a continuous record of ocean bottom seismometers, including tectonic tremors. The upper, middle, and lower panels show the acceleration records, running spectra, and classification results, respectively.

An Examination of Short-Term Preseismic Crustal Deformation that Preceded the 2011 Tohoku-Oki Earthquake

B03 Spatio-temporal multiscale modeling and forecast of slow and fast earthquakes
Hitoshi Hirose (Research Center for Urban Safety and Security, Kobe University)

Attempts to detect possible slow slip (or pre-slip) that occurs immediately before a large earthquake using geodetic measurements have been extensively conducted. If such slip before an earthquake could be detected, it could be useful for short-term earthquake prediction. In addition, such observations could provide important data for understanding the initial process of an earthquake. However, there are very few reliable observations of pre-slip on short timescales, such as a few days or hours.

Recently, Bletery and Nocquet (2023; hereafter BN23) conducted a weighted stacking analysis of high-rate GNSS data (a method that determines coordinates at much shorter time intervals as compared with routine GNSS positioning that estimates one coordinate from one day of data; in this case, a five minute sampling interval), and identified crustal deformation that could be interpreted as accelerated pre-slip near the hypocenter starting about 2 h before the 2011 Tohoku-Oki earthquake (Fig. 1A). However, Bradley and Hubbard (2023), using the same GNSS data and data processing to reduce noise specific to GNSS (i.e., common mode errors), before conducting the same stacking analysis as BN23, did not identify the accelerated deformation just before the mainshock reported by BN23 (Fig. 1B).

We investigated whether the crustal deformation immediately before the mainshock, as claimed by BN23, is recorded by Hi-net tilt records from the National Research Institute for Earth Science and Disaster Resilience (Hirose et al., 2024). The objective of this study was to conduct data analysis similar to BN23 using an independent dataset (i.e., tilt data), which is not affected by the noise specific to GNSS data, and to examine whether the crustal deformation claimed by BN23 can be observed.

Figure 2 shows the results of applying the BN23 stacking method to the tilt records after removing the tidal components. The largest foreshock (M 7.3) occurred at 11:45 on March 9 (just before the time period shown in Fig. 2). Strong motions caused by the foreshocks, which became active thereafter, are clearly evident as spike-like changes. However, apart from these, no significant changes were observed and, in particular, the accelerated change starting 2 h before the mainshock as identified by BN23 is not evident.

However, we cannot conclude that there was no pre-slip before the mainshock simply because it is not evident in Fig.2, as there is always noise in observational data, and signals smaller than the noise level cannot be detected, even if they exist. Therefore, we evaluated the noise level of the data shown in Fig. 2B, and found it to be 5.0×10^{18} Nm. In contrast, the amplitude of the accelerated deformation claimed by BN23 is 2.9×10^{19} Nm in seismic moment, which exceeds this noise level. This indicates that if such pre-slip had occurred, it should have been recorded by the tilt stacking result.

The results of our study support the claim of Bradley and Hubbard (2023) that the accelerated deformation reported by BN23 is likely due to noise in the GNSS data. While this does not completely rule out the possibility of pre-slip before the Tohoku-Oki earthquake, this study has significance in that it constrains the maximum size of any pre-slip, meaning that if pre-slip did occur, it must have been smaller than the noise level.

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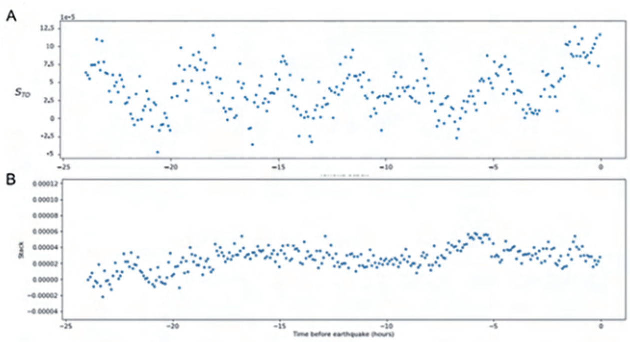


Figure 1: Results of the stacking of GNSS data for 24 h prior to the mainshock. (A) Bletery and Nocquet (2023). (B) Bradley and Hubbard (2023).

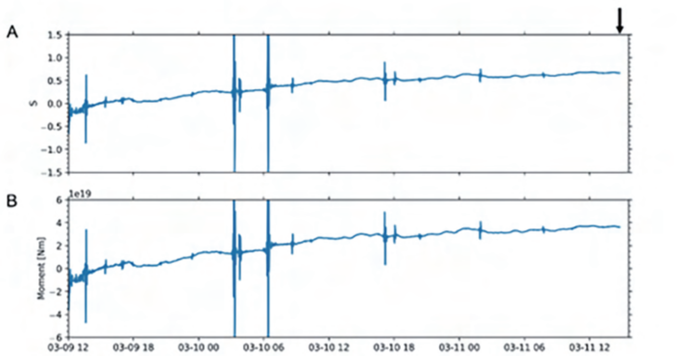


Figure 2: Results of the stacking of tilt data for ca. 51 h prior to the mainshock (Hirose et al., 2024).

Publicly Offered Research in Group A01

Fluid–Rock Reaction Experiments for Understanding the Relationship Between Material Changes and Deformational Properties

Hanaya Okuda (Kochi Institute for Core Sample Research, JAMSTEC)

Along subduction plate boundaries, where slow and fast earthquakes occur, fluid–rock reactions lead to changes in material and deformation properties. These changes can control the depth variations in seismic activity in subduction zones, and previous studies have investigated the relationship between changes in material and deformation properties using pure materials before and after fluid–rock reactions. However, natural rock samples have complex grain sizes and mixtures of materials, which mean that simply using pure materials before and after fluid–rock reactions cannot reproduce natural reaction products. In this study, we first conduct fluid–rock reaction experiments to reproduce the material changes that occur in nature. We then use the reaction products for deformation experiments to understand the relationships between changes in material deformation properties and the factors controlling seismicity in subduction zones. In particular, we are focusing on alteration processes of clay and feldspar minerals, which occur around the updip limit of the seismogenic zone.

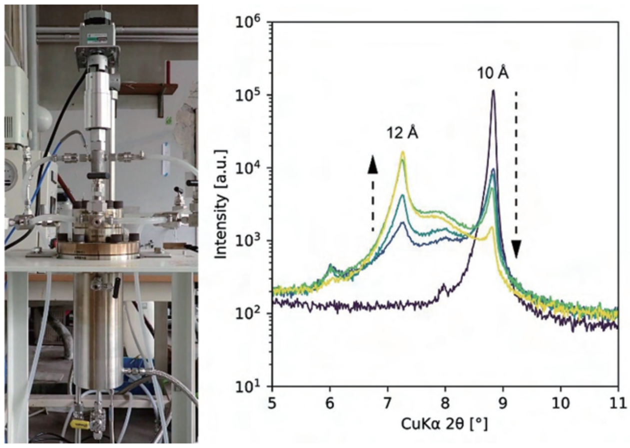


Figure 1: (Left) Hydrothermal reaction vessel at Tohoku University used for fluid–rock reaction experiments. (Right) Alteration of clay minerals due to chemical treatment. A change in crystal structure is evident.

Publicly Offered Research in Group A01

Shear Slip Experiments Under Pore Pressure Conditions Using Fluid Injection of Large Rock Specimens

Yusuke Mukuhira (Institute of Fluid Science, Tohoku University)

Recently, many phenomena similar to slow earthquakes have been observed in the field of resource engineering, where fluid injection is performed, and the involvement of fluids is becoming more explicit. We have been studying induced earthquakes using an experimental apparatus in which a large cubic (60 cm sides) rock specimen is equipped with a water injection device. The injected pore water pressure can be confined to the fault plane, reproducing a pore pressure distribution similar to that of the actual subsurface.

In this study, we found that the shear strain is released gradually near the injection point before fault slip, which corresponds to a fast earthquake, using strain gauges installed in a trench just below the fault plane. Furthermore, by installing an Acoustic Emission (AE) measurement system capable of continuous recording, we aim to comprehensively measure the AE generated by fluid injection and that associated with slow earthquakes (Fig. 1). Along with the strain and pore pressure distributions, we plan to clarify the behavior of the transition from slow to fast earthquakes on the scale of laboratory experiments.

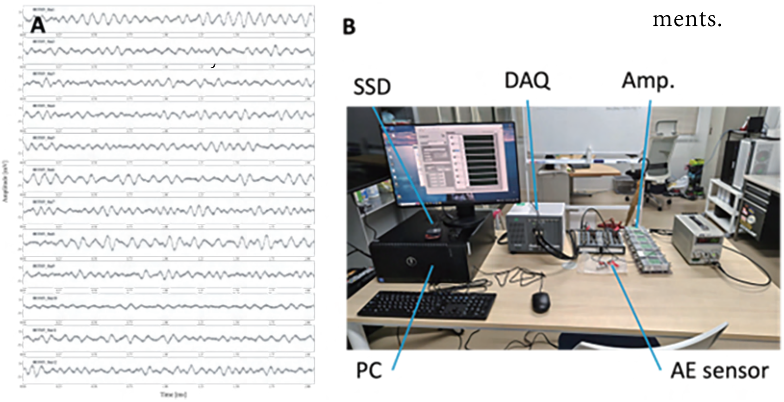


Figure 1: (A) Low-frequency-dominant oscillation acquired during the experiment, possibly emitted by slip corresponding to a slow earthquake. (B) The installed continuous AE measurement system (2 MHz, 18 bits, 16 channels, and 1 h of measurement).

Publicly Offered Research in Group A02

Identifying Structural Factors That Affect Shallow Tectonic Tremor Activity

Takeshi Akuhara (Earthquake Research Institute, The University of Tokyo)

Tectonic tremors are a type of slow earthquake that are detected as weak signals in seismic waveform records. Due to their weak nature, determining the locations of tectonic tremors is challenging, and thus their relationship with geological structures remains elusive. Off the southeast coast of the Kii Peninsula, in Kumano-nada, a seafloor cabled seismic network (DONET) has been in operation for about 10 yr, enabling long-term monitoring of slow earthquake activity. In addition, active source seismic surveys have been intensively conducted in this region to investigate subsurface structures. For these reasons, Kumano-nada is ideal for investigating structural controls on slow earthquakes.

Since 2019, we have deployed a dense array of ocean bottom seismometers in Kumano-nada to observe intense slow earthquake episodes that occur approximately every 5 yr. Using these data, we plan to perform high-precision hypocenter determinations of the tectonic tremors, estimate the 3-D seismic wave (especially S-wave) velocity structure, and identify the geological structures that affect tremor activity.

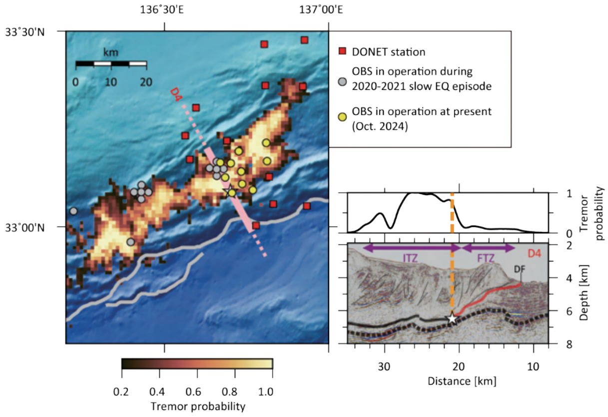


Figure 1: Tectonic tremor activity during the 2020–2021 episode and station distribution (left). Comparison of the tremor activity with the geological structures (right).

Publicly Offered Research in Group A02

Processes and Timescales of Silica-Sealing in Slow-to-Fast Seismogenic Zones Revealed by Laboratory Crack–Seal Experiments

Masaoki Uno (Graduate School of Environmental Studies, Tohoku University)

Silica sealing is one of the main mechanisms for increasing fluid pressure in fault zones, and its timescale is key to understanding the recurrence of slow earthquakes and tremors on plate boundaries. However, no experiments have examined silica sealing under high-pressure and high-temperature conditions, and the processes and timescales of silica sealing remain unclear. We have developed a new, unique hydrothermal flow-through apparatus that allows fluid to flow through a rock sample at a high confining pressure and temperature corresponding to slow-to-fast seismogenic zones (Fig.1). Preliminary experimental results suggest that under an extremely high fluid pressure gradient, the permeability of the fractured rock decreases by 2–3 orders of magnitude in only a few days, and silica-sealing veins repeatedly formed in response to fluid pressure fluctuations. Based on these experiments and field observations of silica-sealing veins (i.e., quartz veins), we will constrain the processes and timescales of fault zone sealing in slow-to-fast seismogenic zones.

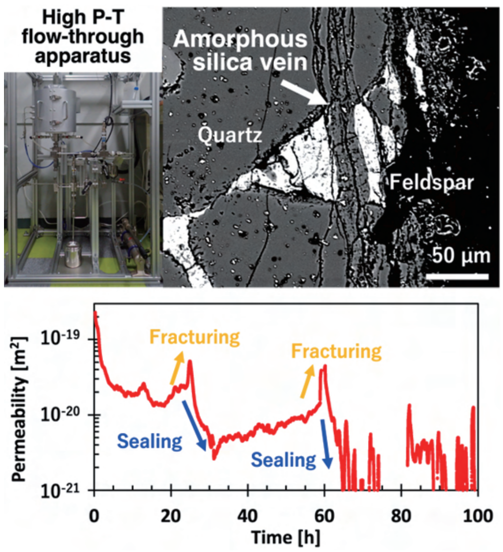


Figure 1: High P–T hydrothermal flow-through apparatus and preliminary results showing silica veins. The back-scattered electron image shows that multiple silica veins formed repeatedly. Permeability monitoring identified two occurrences of sealing and permeability enhancement, corresponding to the multiple generations of silica veins.

Publicly Offered Research in Group A02

Isotopic Research on Geofluids Related to Earthquakes

Yoshiro Nishio (Kochi University)

The origin and behavior of subsurface fluids associated with earthquake swarms and large earthquakes remain unclear. Geophysical information such as the seismic wave velocity and electrical resistivity structure can constrain the distribution of geofluids, but cannot determine the origins of fluids and regions with a low fluid density (e.g., fluid migration). However, groundwater samples contain surface waters. Proxies traditionally used in groundwater research, such as H–O isotopes in water, are strongly affected by the presence of surface waters and seawater. Lithium isotopes were used in this study and are less affected by surface water mixing than other geochemical proxies, and thus can trace the origins and behavior of deeply derived fluids. We are using multiple isotopic systems, including lithium, to investigate the origins of hot spring waters on the Noto Peninsula, where deeply derived fluids were involved in the occurrence of earthquakes (Fig. 1). Furthermore, by comparing time-series observations for groundwater samples near the Median Tectonic Line in Shikoku with the surrounding seismic activity, we are attempting to understand the origin and behavior of subsurface fluids involved in seismic activity.

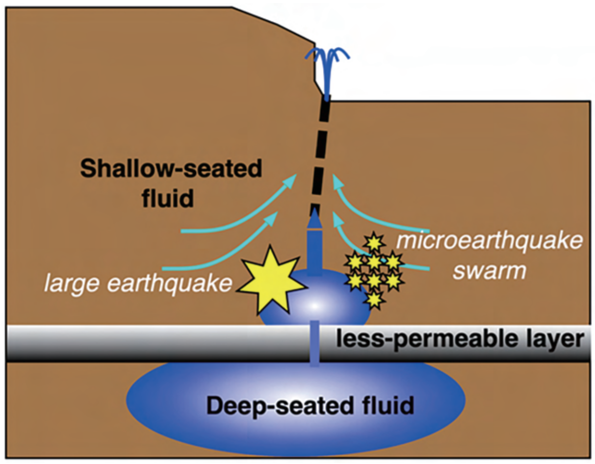


Figure 1: Exploring the deep fluid environment involved in earthquake generation using groundwater isotopes.

Publicly Offered Research in Group A02

Microstructures in Zones of High Pore Pressure: A Coupled Approach Using Shear Tests and Numerical Analysis

Kazuki Sawayama (Graduate School of Science, Kyoto University)

Various observations have indicated a connection between slow earthquakes and zones of high pore pressure. In this study, a coupled scheme combining laboratory shear deformation tests and numerical analysis will be developed to approach the actual conditions of high pore pressure zones. In the laboratory, it is difficult to examine the temporal growth of quartz veins, and it is also difficult to precisely simulate the evolution of fault damage zones by numerical analysis. In this scheme, the growth of fault damage zones is investigated in the laboratory (Fig. 1A), and the timescale is accelerated by numerical analysis (Fig. 1B). A 3D-printed sample is fabricated from the calculated precipitation reaction (Fig. 1C), and the shear deformation experiment is repeated (Fig. 1A). This study will measure changes in geophysical properties during these processes to link geological observations and geophysical observations.

Preliminary numerical analyses have revealed that dissolution–precipitation reactions are accelerated on rough fault surfaces, and that the permeability, seismic velocity, and electrical resistivity exhibit different behaviors depending on dissolution–precipitation process. The relationships between these phenomena and fault strength will be further investigated by combining these results with experiments using laboratory shear testing apparatus.

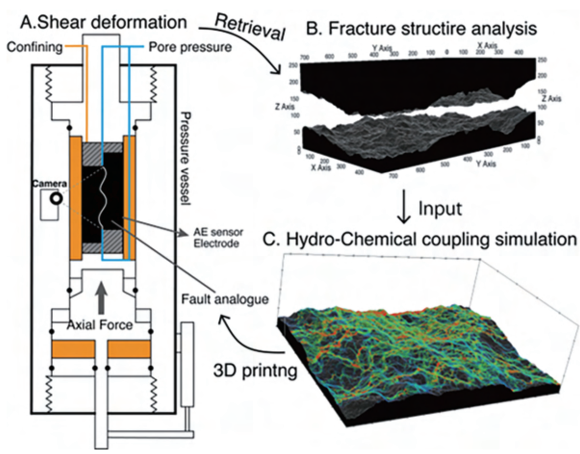


Figure 1: Schematic diagram of the proposed approach to shear testing coupled with numerical analysis.

Publicly Offered Research in Group A03

Data-Driven Seismic Source Detection and Source Process Analyses Without Prior Assumptions

Ryo Okuwaki (University of Tsukuba)

Processes governing the occurrence of both slow and fast earthquakes are being investigated. However, investigations of the mechanisms of slow earthquakes, in particular, are limited to specific regions, such as subduction zones, and may be affected by observational limitations. Recent studies using approaches different from slow earthquake detection have noted the presence of non-earthquake sources hidden in seismic noise, such as tremors caused by the passage of hurricanes and submarine landslides, which are detected in various tectonic–environmental contexts. In this study, we aim to detect and analyze seismic sources and their processes using a data-driven approach, without relying on prior information about slow earthquakes or focusing on specific source types or regions, utilizing dense seismic networks in both Japan and globally. By analyzing seismic sources with an approach not constrained by known mechanisms or regions, and conducting international comparisons, we hope to obtain a unified understanding of slip behavior in slow to fast earthquakes.

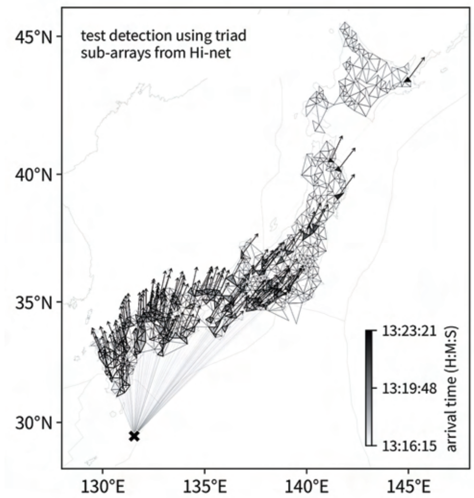


Figure 1: Detection design using the Hi-net high-sensitivity accelerometer records, and an example of the detection of an unknown seismic source using the triad sub-arrays. The cross symbol indicates the source location. The arrow indicates the arrival angle at the triad sub-array. The color indicates the arrival time.

Publicly Offered Research in Group B01

Development of a Seafloor Pressure Data Analysis Method Resistant to Instrumental Characteristics and Environmental Disturbances

Keisuke Ariyoshi (Yokohama Institute for Earth Sciences, JAMSTEC)

Borehole pore pressure measurements in the Nankai Trough (Kumano-nada) represent one of the few datasets capable of real-time detection of shallow strain release processes, such as slow slip events (SSEs), which are difficult to be captured with land-based observational networks. However, since the pore pressure is measured using quartz pressure gauges installed within the borehole, at the borehole head, and on the seafloor (Dense Ocean floor Network system for Earthquakes and Tsunamis; DONET), it is affected by: (a) external disturbances, (b) instrumental drift, and (c) seismic motion. This can complicate fault model estimates for SSEs. This study aimed to identify and mitigate these noise factors through international collaboration using: (a) a quantitative approach with the ocean model Japan Coastal Ocean Experiment (JCOPE), (b) laboratory environmental experiments, and (c) comparative verification with broadband seismometers.

In this fiscal year, we demonstrated that the diversity of SSEs may be caused by oceanic disturbances associated with meandering of the Kuroshio, based on a comparison of JCOPE reanalysis data with seafloor and borehole pressure gauge data (Fig. 1). This result is part of our ongoing collaborative research with the University of Texas at Austin, and we plan to further deepen international collaboration through this project.

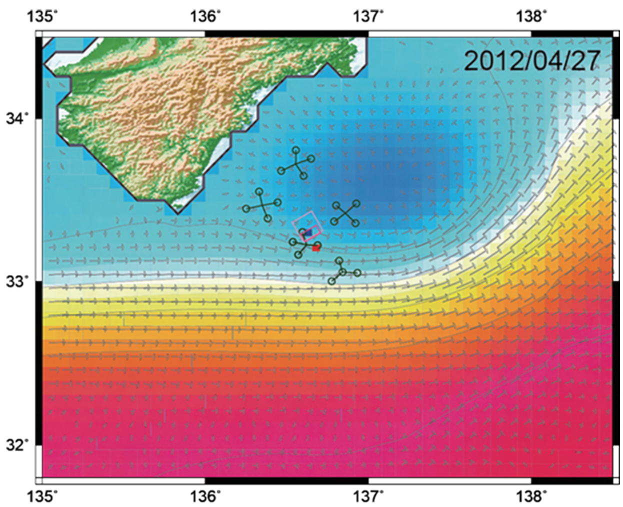


Figure 1: Spatial distribution of the sea surface height anomaly (color; [actual sea surface height] – [mean sea surface height]) and current velocity (arrows) calculated from JCOPE (Ariyoshi et al., 2024). The pink shading represents the fault model for the SSE that began in February 2012. Circles denote DONET seafloor pressure gauges, and squares (blue and red) represent borehole observation points. The development of a cyclonic circulation associated with the countercurrent of the Kuroshio meander led to a drop in the sea surface height until late April, resulting in a steady decrease in seafloor pressure. This reduction in frictional force suggests that, despite the magnitude of the SSE, it may have persisted for an unusually long period.

Publicly Offered Research in Group B02

Rapid Hypocenter Determination Tool for the Nankai Trough Subduction Zone Using Physics-Informed Neural Networks

Ryoichiro Agata (Research Institute of Marine Geodynamics, JAMSTEC)

Accurate hypocenter determination is crucial in the Nankai Trough (NT) region, where the occurrence of a megathrust earthquake is anticipated. To improve the accuracy of hypocenter determination, it is necessary to accurately calculate the travel times of seismic waves from the hypocenter to observational points on Earth's surface. For accurate travel time calculations, it is essential to incorporate the three-dimensional (3D) heterogeneous seismic velocity structure beneath the subduction zone in the calculations. However, due to the high computational cost, simplified velocity structures that require less computational cost are widely used.

In this study, we developed a tool called HypoNet Nankai that performs fast and easy-to-use travel time calculations and hypocenter determinations by incorporating the 3D velocity structure of the NT using physics-informed neural networks (PINN). HypoNet Nankai contains a pre-trained deep learning (DL) model that has learnt the travel times between any source underground and observational points on the surface in the target velocity model of the NT (Fig. 1). The training incorporates information from the eikonal equation through PINN, without requiring any labeled data. Once deployed, this model can instantly output travel times between any hypocenter and observational points using a laptop. This enables fast and efficient hypocenter determination.

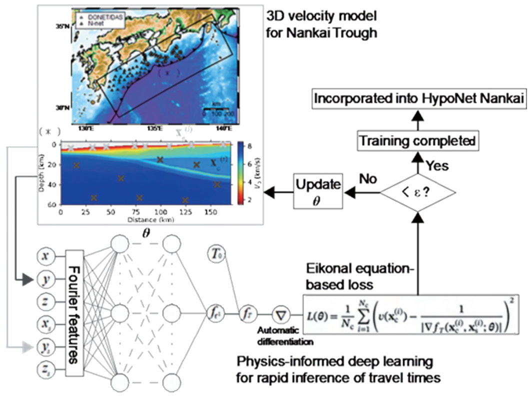


Figure 1: Schematic of the DL model incorporated in HypoNet Nankai. The DL model was formulated to predict travel times for source–observational point pairs. The residuals of the governing equations (i.e., the eikonal equation) for the predicted travel times of each pair were evaluated for random samples of source–observational point pairs from the 3D velocity structure model. The DL model was trained until the loss function, which consists of the sum of the squared residuals, became sufficiently small.

Publicly Offered Research in Group B03

What Controls the Thrust Vergence in Subduction Zones — Insights From Numerical Sandbox Experiments

Jian Chen (Center for Mathematical Science and Advanced Technology, JAMSTEC)

Accretionary wedges, such as those in the Sumatra and Cascadia subduction zones, exhibit complex deformational structures (Fig. 1), with landward-vergent thrust faults often associated with shallow earthquake ruptures. An intriguing scientific question is concerned with the key controlling factors that determine the fault vergence patterns. In this study, we use the discrete element method (DEM) to create numerical sandbox models that simulate the subduction process by replicating thrust faults observed in the field. By systematically varying parameters such as the wedge geometry (backstop and dip angles), sediment properties (frictional contrasts and rolling resistance), and pore fluid lubrication, we aim to determine how these factors affect fault vergence. Our approach with DEM simulations also introduces new features (rolling resistance and fluid lubrication) that have effects on strain localization and fault vergence that remain poorly understood. By integrating the simulation results with geological observations, we aim to provide new insights into the key controls on vergence patterns in accretionary wedges and contribute to a better understanding of subduction zone processes.

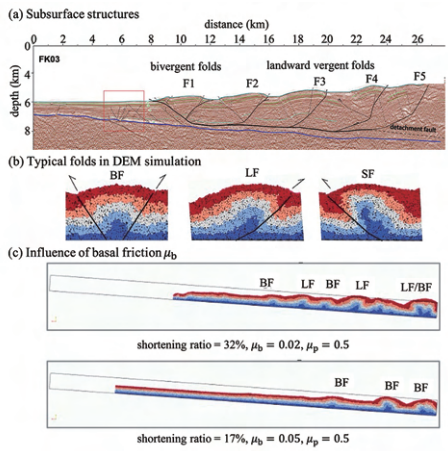


Figure 1: (a) Subsurface structures in the unruptured zone of the central Sumatra subduction zone. The bivergent and landward-vergent folds at the toe of the wedge may contribute to future tsunami generation if an earthquake rupture propagates to a shallow depth. (b) Typical folds observed in numerical sandbox experiments. BF, LF, and SF represent bivergent, and landward- and seaward-vergent folds, respectively. (c) Effect of basal friction μ_b on the deformational structures at a fixed inter-particle friction μ_p. This study will further investigate the effect of other controlling factors, including wedge geometry and fluid lubrication.

A02 - RC

Junichi Nakajima
Professor, Institute of Science Tokyo

Specialty：Seismology
Keyword:Seismotectonics in subduction zones, Seismic tomography

A02 - RC

Yuya Akamatsu
Researcher, Research Institute for Marine Geodynamics, JAMSTEC

Specialty：Rock physics
Keyword：Crack, Fluid flow, Seismic velocity

A02 - RC

Yoshiro Nishio
Associate Professor, Kochi University

Specialty：Geofluid Science, Isotope Geochemistry
Keyword：Geochemical cycle, Geofluid, Groundwater

A03 - RC

Bogdan Enescu
Associate Professor, Graduate School of Science, Kyoto University

Specialty：Seismology
Keyword：Seismicity, Earthquake triggering, Crustal structure

A03 - RC

Ryo Okuwaki
Assistant Professor, University of Tsukuba

Specialty：Seismology
Keyword：Earthquake and non-earthquake source processes

A03 - RC

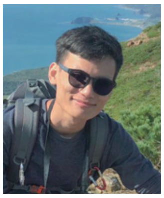
Keisuke Yoshida
Associate Professor, Graduate School of Science, Tohoku University

Specialty：Seismology
Keyword：Observational seismology, Rupture pattern, Crustal stress

A03 - RC

Isaías Bañales
Postdoctoral Research Fellow, Disaster Prevention Research Institute, Kyoto University
Specialty：Bayesian Statistics, Stochastic simulation
Keyword：MCMC, Attenuation laws, ETAS model, Neural networks

A03 - RC



Thomas Yeo
Researcher, Graduate School of Science and Technology, University of Tsukuba

Specialty：Structural geology, Tectonics
Keyword：Crustal deformation, Ductile deformation, Fracturing

B01 - RC

Keisuke Ariyoshi
Senior Researcher, Yokohama Institute for Earth Sciences, JAMSTEC
Specialty：Seismology
Keyword：Seafloor crustal deformation, Theoretical analysis of slip propagation process, Oceanic perturbations

B01 - RC

Yuji Itoh
Assistant Professor, Earthquake Research Institute, The University of Tokyo

Specialty：Crustal deformation
Keyword：GNSS, Slow earthquakes, Earthquake cycle

B01 - RC

Satoru Baba
Postdoctoral researcher, Research Institute for Marine Geodynamics, JAMSTEC
Specialty：Marine seismology, Slow earthquakes
Keyword：Slow earthquakes, Offshore seismic observation, Distributed acoustic sensing (DAS)

International Joint Workshop on Slow-to-Fast Earthquakes 2024

International Joint Workshop on Slow-to-Fast Earthquakes 2024 @Beppu

Satoshi Ide, Graduate School of Science, The University of Tokyo

From September 17 to 19, the International Joint Workshop on Slow-to-Fast Earthquakes 2024 was held at B-Con Plaza in Beppu, Oita. A pre-workshop field trip and early career events were conducted before the meeting, while a post-workshop field trip followed, making for a very eventful week. This was the first fully onsite meeting in five years, and it was our largest event to date with a total of 205 participants from both Japan and abroad. This year's special topics were as follows, in the program order.

- The 2024 M 7.6 Noto earthquake and seismic swarm.
- Induced or controlled earthquakes: what determines the initiation of slow and fast earthquakes?
- Fault rheology of plate boundaries on laboratory, outcrop,and geophysical exploration scales.

The first day focused on the Noto earthquake, which was an event of significant importance for Japan. In addition to highlighting cutting-edge research in Japan, we were able to engage in comparative discussions with ongoing research on earthquakes in Italy, which has made considerable progress in recent years. On the second day, presentations on induced earthquakes introduced observational, experimental, and theoretical studies concerning materials such as veins, clay, and water, which have key roles in these phenomena. The final day featured research results from subduction zones, exploring the connections between laboratory studies and natural settings. In total, there were 32 oral presentations. The poster session featured 153 presentations, fostering vibrant discussions, although many attendees felt more time was needed for deeper discussion. We recognize that improvements in the session structure are necessary. On the second day, participants engaged in discussions during six breakout sessions. While the time was somewhat limited to reach in-depth conclusions, these sessions provided valuable opportunities for networking and identifying key challenges in the field.

The social event on the first day was also a great success. Beppu City, as the host venue, proved to be an ideal setting for fostering connections amongst participants. Throughout the event, we saw participants spontaneously meeting and engaging with each other in various locations in the city. Beppu was a fascinating destination, not only for international participants, but also for Japanese attendees.

This workshop was co-hosted by the Earthquake Research Institute, the University of Tokyo, and the Disaster Prevention Research Institute, Kyoto University, with support from Beppu City and Oita Prefecture. We would like to express our gratitude to the LOC members led by Yoshihiro Ito and Kazuki Sawayama, and all participants and collaborators who contributed to the success of this event.

Pre-Meetiing Field Trip: Mist and Steam in Yufuin Onsen

Yoshihiro Ito, Disaster Prevention Research Institute, Kyoto University

A pre-meeting field trip took place on September 15, the day before the 2024 International Joint Meeting on Slow-to-Fast Earthquake, in the scenic surroundings of Beppu. Despite the rainy morning, the weather improved by lunchtime, contributing to a highly successful excursion. The trip was attended by 55 participants and began at the Zyakoshi Observatory. Shrouded in mist, the observatory provided a mystical backdrop as attendees discussed the tectonics and seismic activity of the Yufuin Onsen area, particularly that following the 2016 Kumamoto earthquake.

The next stop was Yunotsubo Kaido Street, where participants had the opportunity to engage in shopping, enjoy lunch, and relax in the hot springs. The final destination was the trailhead at the base of Mount Yufu-dake. Under a clear blue sky, the group captured a memorable photograph before taking a leisurely walk around the area. This relaxed yet informative outing served as an excellent ice-breaker and set a positive tone for the meeting commencing the next day.

Group photograph in front of Mount Yufu-dake.

Post-Meeting Field Trip: Fossil Evidence of Slow and Fast Earthquakes in Subduction Zones

Asuka Yamaguchi, Atmosphere and Ocean Research Institute, the University of Tokyo

On September 20–21 2024 during the post-meeting field trip of the International Joint Workshop, we visited Nobeoka City in Miyazaki Prefecture to observe fossil evidence of slow and fast earthquakes in subduction zones, which are preserved in the accretionary complex of the Shimanto Belt. At Stop 1 (Makimine mélange at Nomi) there were lively discussions about the ductile deformation of tectonic mélange, mineral veins recording a reversal of the principal stress axis, and metamorphosed basalts. At Stop 2 (Kitagawa Group at Shimoaso), we observed metamorphic foliation overprinting bedding planes. There was also a lively discussion about the depositional environment and deformation of the accretionary complex. All 53 participants joined the social gathering on September 20 and enjoyed local Miyazaki cuisine and shochu, which helped foster closer connections. At Stop 3 (Nobeoka thrust at Tomi), we split into two groups: the Fault Course and Safety Course groups. In the Fault Course, participants descended a steep cliff above a fault outcrop to observe the fault core, pseudotachylyte, and damage zones of the hanging wall and footwall of the Nobeoka thrust. In the Safety Course, we observed the tectonic mélange in the footwall of the thrust, where brittle deformation is prominent. It was impressive to see participants from diverse backgrounds, ages, genders, nationalities, and fields of expertise actively engaging in discussions at the outcrops.

Group photograph of the field trip participants at Stop 2.

Young Researchers and Diversity Promotion

Mixing Events for Early Career Researchers Organized by the Science of Slow-to-Fast Earthquake Project

Yuji Itoh, Earthquake Research Institute, The University of Tokyo

The Science of Slow-to-Fast (SF) Earthquakes project organizes mixing events for early career researchers (ECRs) during large conferences. We organized two events this year. During the Japan Geoscience Union meeting in late May, we held an event for discussions on the careers of students and ECRs. This event aimed to create an opportunity to share ideas, worries, and perspectives about career pathways and research, as well as to discuss these various topics frankly with researchers whose careers are slightly more advanced than those of the participants.

The discussion was led by four researchers in our Science of SF Earthquake project who have experienced very different career pathways: Mari Hamahashi (former post-doctoral fellow abroad, and now a lecturer at Yamaguchi University), Yuta Amezawa (a graduate from a regional university, and now assistant professor at the Institute of Science, Tokyo), Koki Masuda (working in the private sector after completing a doctoral degree), and Hinako Hosono (tenured researcher at the National Institute of Advanced Industrial Science and Technology since completing a Master's degree). We welcomed about 30 ECRs, and they exchanged their various opinions with each other.

The second event was an ECR poster session held on the day before the International Joint Workshop on Slow-to-Fast Earthquakes 2024 in the middle of September. We welcomed about 70 highly motivated registered participants, and they vigorously discussed their research by bringing their posters prepared for the main workshop. One even prepared their poster exclusively for this ECR poster session. Many international ECR event participants were able to catch up with their close friends and colleagues. This event offered an opportunity for ECRs to mix in a relaxing atmosphere, which fostered connections between future seismologists and solid earth scientists.

Annual Report 2024 from the Young Researchers and Diversity Promotion Task Force

Saeko Kita, Building Research Institute

As a member of the Young Researchers and Diversity Promotion Task Force, here I provide an annual report for 2024. We have held exchange events called the "Slow-to-fast Earthquakes Project Café" four times. The first café event was held in February at the AORI, University of Tokyo. In the first half of the meeting, there was two research seminars (hybrid-style) aimed at sharing and discussing information about the Noto Peninsula earthquake. In the second half, we had a breakout session (in-person) on the theme of "What do you want to do and what should you do before and after occurrences of large earthquakes?". The second café event was held in mid-August at Kyoto University (hybrid-style). In the first half of this event, Dr. Yoshihiro Kaneko (Kyoto University) gave a presentation entitled "Simulating Earthquake Waves in the Atmosphere and Ionosphere" and a Q&A session related to his overseas career. In the second café event, we also shared information regarding, and discussed, the 2024 M 7.1 Hyuga-nada earthquake in the Nankai Trough and following emergency, which was hastily organized in response to the occurrence of the M 7.1 event on August 8, 2024. The third café event was held at the end of August to promote diversity within our scientific project at the ERI, University of Tokyo. The fourth café was a collaborative seminar with JAMSTEC, in which Ms. Amy Woodward, a graduate student at Imperial College London in the UK, gave a presentation about the analysis of seismicity associated with slow slip on the Hikurangi subduction margin. The fifth café was also a collaborative seminar with the ERI, University of Tokyo, in which Dr. Kelin Wang (Geological Survey of Canada) gave a presentation on the geodynamics of slow earthquakes. We also provided opportunities for 30-min research discussions between overseas researchers and young and mid-career researchers. Professors Anne Socquet (Université Grenoble Alpes, France), Alex Schubnel (École Normale Supérieure), and Heidi Houston (University of Southern California) had individual discussions with each young researcher who had requested a one-on-one discussion via Zoom.

A photo in the first Slow-to-fast Earthquakes Project Café (February, 2023)

Self-invited workshop on SF Earthquake Science in Mexico

Slow-to-Fast Earthquake Workshop in Mexico: Botanical Garden at 2400m Elevation and Volcano Observatory at 4000m Elevation

Yoshihiro Ito, Disaster Prevention Research Institute, Kyoto University

On February 26–27 2024, the International Joint Workshop on Slow-to-Fast Earthquakes in Mexico was held at the National Autonomous University of Mexico in Mexico City. This event was organized in conjunction with the Integrated Research Group for Megathrust Earthquakes along the Nankai Trough, which is a part of the Second Earthquake and Volcano Hazards Observation and Research Program. The workshop showcased cutting-edge research in slow-to-fast seismology and highlighted efforts in Japan and Mexico to mitigate earthquake and tsunami disasters.

The event was well attended, with a total of 68 participants, including 22 from Japan. Over the 2 days, 32 oral and 26 poster presentations sparked vibrant discussions, set against the backdrop of the university's picturesque gardens.

Following the workshop, on February 28–29, participants engaged in a field trip led by Mariana Patricia Jácome Paz from the Institute of Geophysics at the National Autonomous University of Mexico. The first day included visits to the monogenetic volcano Xitle and the National Centre for Disaster Prevention (CENAPRED) in Mexico City. The following day attendees explored the area surrounding Popocatépetl volcano, situated approximately 70km southeast of Mexico City and the nearby volcano observatory, located 5km north of the crater at about 4000m above sea level.

This workshop and subsequent field trip provided valuable opportunities for researchers and students from both countries to share their latest research and technological advances. The National Autonomous University of Mexico made a video of the workshop that is available on YouTube, which offers further insights into the discussions and presentations. You can view it here:
https://www.youtube.com/watch?v=wTHh-4SfsGY

YouTube Channel
< Instituto de Geofísica, UNAM >

Group photograph with the majestic Popocatépetl volcano (5426 m above sea level) erupting in the background.

Report on Cargèse 2024 School on Subduction Zone Processes

Corsica Summer School

Aitaro Kato, Building Research Institute

A summer school was held during October 14–18 2024 at the Institut des Études Scientifiques in Cargès, Corsica, France. Six people from the Science of Slow-to-Fast Earthquake Project, including myself (Yoshihiro Kaneko, Kurama Okubo, Daisuke Sato, Diana Mindaleva, Ritsuya Shibata, and Reiju Norisugi), participated. The theme of this school was "EARTHQUAKES: nucleation, triggering, rupture, and relationships to aseismic processes—4th edition" and it was the first time in about three years that a school with this theme had been held. It was an international school with a total of 90 people from 16 countries (25 nationalities). Lectures and research presentations were given on research topics closely related to our project from various observational, theoretical, and experimental aspects, such as "The Complete Slip Spectrum" on the first to second days, "Earthquake Nucleation and Triggering" on the second to third days, "The Earthquake Cycle" on the fourth day, and "Natural and Induced Hazards" on the final day, followed by lively Q&A sessions and discussions. In addition, in the evenings of the first to fourth days, poster sessions were held outdoors, and participants continued their enthusiastic discussions until late into the night. In the first half of the afternoon of each day, practical tutorials on data analysis and numerical simulation methods, group discussions overlooking the sea, and other activities were held, providing opportunities for participants to deepen their interactions. In addition to gaining cutting-edge knowledge on earthquake science, we were able to have in-depth discussions with researchers at the forefront of each field. It was a rare opportunity to broaden our research horizons, and if you have not yet participated, please consider participating in the Corsica Summer School in the future.

Group photograph at the Institut des Études Scientifiques

Visiting researcher program for young researchers

Collaborative Research at École Normale Supérieure, France

Ryo Nakagawa, Graduate School of Science, Tohoku University

From June to August 2023, I conducted joint research under the supervision of Professor Romain Jolivet at the École Normale Supérieure in Paris, France. The research focused on developing a deep learning method to detect short-term slow slip events (SSEs) along the plate boundary in western Shikoku based on GNSS displacement data. By leveraging deep learning, which eliminates the need for hyperparameter tuning and data preprocessing to improve the signal-to-noise ratio, we aimed to simplify and enhance the accuracy of SSE detection.

Professor Jolivet's group has developed methods to extract millimeter-scale deformation from InSAR time-series data. Building on their expertise, we engaged in discussions that extended beyond current approaches to estimate only spatial slip distributions. These discussions also included ideas for detecting short-term SSEs in both time and space using time-series data from multiple GNSS stations.

At present, we have refined the tuning of the model and assessed it under many conditions. We are carefully examining under what conditions this method can surpass a conventional inversion method. Once this method is fully established, I plan to apply it to the spatiotemporal detection of short-term SSEs in western Shikoku and, eventually, to develop a detection method applicable to other regions.

Visiting Research at the Université of Grenoble Alpes

Taku Ueda, Disaster Prevention Research Institute, Kyoto University

From May 18 to July 7 2024, I stayed at the Université of Grenoble Alpes for joint research with Professor Anne Socquet. In Grenoble, we conducted research on the estimation of the strain rate field using horizontal velocities estimated from GNSS data in Europe and participated in a benchmark test to apply and compare multiple strain-rate field estimation methods to synthetic datasets that assume the distribution of GNSS stations and crustal deformation in France. By conducting new research on Europe, which is a tectonic setting that differs greatly from Japan, I was able to deepen my knowledge of strain rate estimation methods. We plan to continue our joint research in the future. In addition to this research, I was able to connect with several researchers through discussions with Professor Roland Bürgmann (University of California, Berkeley) and Professor David Marsan (University of Savoie Mont Blanc). I would like to express my sincere gratitude to all the people involved in the Science of Slow-to-Fast Earthquake project and the secretariat for supporting this overseas research. I hope to make positive use of this experience in my future research.

Professor Anne Socquet (right) and myself.

Visiting researcher program for young researchers

Collaborative Research at École Normale Supérieure, France

Chengrui Chang, Department of Biomaterial Sciences, The University of Tokyo

I was honored to receive funding from the SF project to visit academic institutions in the U.S. from January to March 2024. During this time, I gained invaluable experience through laboratory work, scientific discussions, and collaborations.

At UC Santa Cruz, I joined Emily Brodsky's seismology laboratory and investigated granular shear flow friction. The supportive team, including Emily, Huiyun, and Will, inspired me with their quantitative and logic skills. Morning “seismo coffee” sessions, laboratory work, and lunch discussions created stimulating collaboration. Weekly seminars encouraged the exchange of ideas, while the campus offered relaxing moments for exploration.

In March, I visited the USGS Landslide Program in Golden, Colorado, hosted by Bill Schulz. I had the privilege of exploring the Slumgullion landslide, guided by Bill. We retrieved monitoring data, discussed kinematic models, and examined fault systems, gaining insights into shear systems in nature. This trip deepened my understanding of earthquakes and landslides, equipping me with knowledge and skills to advance my research.

Morning “seismo-coffee” discussion.

Collaborative Research at the University of California, Berkeley

Yanhan Chen, Disaster Prevention Research Institute, Kyoto University

From June 26 to September 9 2024, I carried out my overseas research at UC Berkeley. My focus was on combining deep learning with low-frequency earthquakes (LFEs), working in Professor Weiqaing Zhu's group. I attempted to train a comprehensive LFE model by collecting LFE catalogs from major subduction zones, including Nankai, Cascadia, New Zealand, Parkfield, Alaska, and Mexico. Because LFEs differ from regular earthquakes, I invested a lot of time and effort in selecting and labeling the LFE dataset, which also enhanced my programming ability to process large amounts of different network waveform data.

During my stay, I visited Takaaki Taira san, a seismologist at Berkeley Seismology Laboratory. I also had several discussions with Professor Roland Bürgmann who invited me to give a presentation at their active tectonics meeting on my Guerrero Seismic Gap research and my plans for future research. This overseas experience broadened my horizons. Through discussions with several seismologists, I realized the importance of active dialogue and collaborative research.

Toyama Hot Spring Camp 2024: Kintaro Hot Spring and Curry Rice

Yoshihiro Ito, Disaster Prevention Research Institute, Kyoto University

A winter camp seminar in the format of a science retreat was held during February 8–10 2024 at Fureai Koryukan Akoya-a-no in Kurobe City, Toyama Prefecture. This event, organized as part of a scientific workshop, attracted 25 participants, including members of the A02 and B01 research groups, as well as fourth-year undergraduates, in addition to participants from the A03 group. Numerous international students also attended, with several presentations delivered in English.

The seminar featured two invited speakers from Kyoto University: Takashi Nishizawa and Yohei Nozue. They shared valuable insights on diverse topics such as the global variability of subduction zones, advanced inversion techniques for strain rate field analysis, and findings from a field survey conducted on the Noto Peninsula, where the January 1 2024 Noto earthquake occurred. The presentations provided a comprehensive overview of the latest research on slow and fast earthquakes from a wide range of perspectives, such as observational data, experimental approaches, and numerical modeling.

The venue, Fureai Koryukan Akoya-a-no, evoked a sense of nostalgia, resembling the accommodation facilities typically used during elementary school excursions. The lunch provided, including a curry dish, brought back memories of school meals. Accommodation options included communal rooms with bunk beds and spacious tatami rooms, fostering a setting where discussions could continue informally even beyond the seminar sessions.

Participants also engaged in camp-specific activities, such as a tour of a nearby hot spring facility, which featured discussions on metamorphic rock samples integrated into the bath area, and a social gathering where participants enjoyed food and drinks from a local supermarket. The camp offered a unique opportunity for both scientific exchange and informal interactions in a relaxed setting.

Group photograph in front of the entrance to the Fureai Koryukan Akoya-a-no.

JTRACK Revisiting the hypocentral region

Kohtaro Ujiie
Graduate School of Science and Technology, University of Tsukuba

Tracking Tsunamigenic Slip Across the Japan Trench (JTRACK) is a project scheduled for September 6 to December 20 2024 as part of the International Ocean Discovery Program Expedition 405 by the deep drilling vessel Chikyu. The target area for drilling is the Japan Trench off Miyagi, where the largest slip occurred during the 2011 Tohoku-Oki earthquake. In 2012, the Integrated Ocean Drilling Program Expedition 343 Japan Trench Fast Drilling Project (JFAST), also conducted by the Chikyu, collected geological samples from the plate boundary fault and succeeded in capturing the frictional heat during the earthquake. The results showed that the friction in the shallow part of the plate boundary fault was extremely low during the earthquake, which caused the large slip. However, it remains unclear whether the large slip was caused by stress accumulation in the shallow part of the plate boundary or by seismic rupture propagation from deeper parts of the fault. JTRACK will conduct logging-while-drilling, collection of geological samples, and installation of long-term borehole thermometers to study: (1) the state of stress accumulation around the shallow part of the plate boundary fault and changes in the stress field 13 years after the earthquake; (2) the structural, physical, frictional, and hydraulic properties of the frontal prism, plate boundary fault, and subducting plate; and (3) changes in material, structural, physical, frictional, and hydraulic properties before and after subduction. By obtaining information regarding (1)–(3), JTRACK aims to determine the factors controlling large shallow slip on faults and provide new insights into, and information on, megathrust earthquakes and large tsunamis in subduction zones. Some members of the slow-to-fast earthquake project also participate in JTRACK as a co-chief scientist and scientists.

Lecture

Lecture at the Nanki–Kumano Geopark Center

Asuka Yamaguchi, Atmosphere and Ocean Research Institute, The University of Tokyo

In Group A02, we have been collaborating with the Nanki–Kumano Geopark since the establishment of our project. As part of this ongoing effort, the 7th Annual Nanki–Kumano Geopark Center Lecture was held on January 15 2024 at the Nanki–Kumano Geopark Center in Kushimoto Town, located at the southernmost tip of the Kii Peninsula at Cape Shiono. Last year, Dr Saeko Kita from Group A02 was the lecturer, while this year, Professor Ide had this role. He delivered a 90-minute lecture entitled “Earthquake Prediction and Slow Earthquakes” covering the basics of earthquakes to the latest research findings. Following the lecture, there was a lively question-and-answer session. During the event, support was provided with sign language interpretation and note-taking (pictured), highlighting the commitment of local government to widely disseminating information regarding disaster preparedness for the anticipated Nankai Trough earthquake. We extend our sincere gratitude to everyone who coordinated and made this lecture possible. The event was featured on the NHK evening news that day and also in three local newspapers. The event format was in-person with sign language interpretation and note-taking support, and was co-hosted by the Wakayama Prefectural Nanki–Kumano Geopark Center and the Science of Slow-to-Fast Earthquake project.

Lecture at the Nanki–Kumano Geopark Center given by Professor Satoshi Ide.

Award

Elected as a member of the Academy of Sciences of Turin
Wallis R・Simon (A02; Co-investigator/University of Tokyo)

2023 Young Scientist Award of the Seismological Society of Japan
Tomoaki Nishikawa (B02; Publicly Offered Collaborator/Kyoto University)

2023 Research Paper Award of the Seismological Society of Japan
Tomoaki Nishikawa (B02; Publicly Offered Collaborator/Kyoto University);
Satoshi Ide (Principal Investigator/University of Tokyo) and others
Akiko Takeo (B02; Co-investigator/University of Tokyo) and others

Outstanding Student Presentation Award of the Geological Society of Japan (130th) *excluding those in Vol. 3
Hiyori Abe (A02; Student/Shizuoka University)
Taisei Kimura (A02; Student/Shizuoka University)

Young Groundwater Researcher Grant Encouragement Award of the Japanese Association of Groundwater Hydrology
Manato Akishiba (A02; Student/Kochi University)

Outstanding Presentation of Shikoku Branch, the Geological Society of Japan (23st)
Zahra Zandvakili (A02; Student/Kochi University)

Outstanding Student Presentation Award of JpGU 2024
Reiju Norisugi (A01; Student/Kyoto University)
Taizo Uchida (A02; Student/Kochi University)

The Clay Science Society of Japan (CSSJ) Young Researcher's Award
Hanaya Okuda (A01; Publicly Offered Collaborator/JAMSTEC)

The Geological Society of Japan Sakuyama Masanori Award
Hanaya Okuda (A01; Publicly Offered Collaborator/JAMSTEC)

The Geological Society of Japan H. E. Naumann Award
Atsushi Okamoto (A01; Publicly Offered Collaborator/Tohoku University)

The Geological Society of Japan Koto Bunjiro Award
Atsushi Okamoto (A01; Publicly Offered Collaborator/Tohoku University)

AGU Mineral and Rock Physics Graduate Research Award
Hanaya Okuda (A01; Publicly Offered Collaborator/JAMSTEC)

AGU's Outstanding Reviewer Award 2023
Akemi Noda (B03; Collaborator/JMA)

2024 Young Scientist Award of the Seismological Society of Japan
Ryoichiro Agata (B02; Publicly Offered Collaborator/JAMSTEC)
Yuki Kodera (B02; Co-investigator/MRI)

2024 Technical Development Award of the Seismological Society of Japan
Futoshi Yamashita (A01; Co-investigator/NIED)and others
Eiichiro Araki (B01; Co-investigator/JAMSTEC)and others

The 32nd Tsuboi Prize of the Geodetic Society of Japan
Yuta Mitsui (B02; Co-investigator/Shizuoka University)

Outstanding Student Presentation Award of the Geodetic Society of Japan (142th)
Riko Arai (B02; Student/Shizuoka University)
Kohei Shimotsuma (A03; Student/University of Tsukuba)
Miku Ohtate (B02; Student/Tohoku University)

Outstanding Student Presentation Award of the Geological Society of Japan (131st)
Manamu Miyazoe (A01; Student/Kyoto University)
Shuhei Fujiwara (A01; Student/Tohoku University)
Shunya Okino (A01; Student/Tohoku University)
Satoshi Matsuno (A02; Student/Tohoku University)
Ryoto Toda (A02; Student/Tohoku University)
Natsuki Nomura (A01; Student/Kochi University)
Yukinojo Koyama (A02; Student/University of Tokyo)
Yuto Yamasaki (A03; Student/University of Tsukuba)

Outstanding Student Presentation Award of the Seismological Society of Japan
Reiju Norisugi (A01; Student/Kyoto University)
Shukei Ohyanagi (A03; Student/Kyoto University)
Miku Ohtate (B02; Student/Tohoku University)

2024 Outstanding Research Presentation Award of the Japan Association of Mineralogical Sciences
Kentaro Toda (A01; Student/Tohoku University)
Satoshi Matsuno (A02; Student/Tohoku University)
Masayoshi Hoshida (A02; Student/Tohoku University)

Introduction of the Slow-to-Fast Earthquakes Official Social Networking Service (SNS)

Website　Facebook　X

Publication of Slow-to-Fast Earthquake Leaflet in Spanish

In 2022, we created a leaflet in both Japanese and English to introduce slow and fast earthquakes. In 2023, we additionally prepared the Spanish version for the upcoming self-invited workshop in Mexico, 2024. The pdf version is available on the Slow-to- Fast Earthquakes website. For the printed copies, please contact us from the Contact Form on the website.

Upcoming Events

Japan Geoscience Union Meeting 2025
Date: May 25 (Sunday) to 30 (Friday) 2025
Hybrid (in-person and online)
Venue: MAKUHARI MESSE, Chiba

International Joint Symposium on Slow-to-Fast Earthquakes 2025
Date: September 24(Wednesday) to 26 (Friday) 2025
Venue: Kochi-city Culture Plaza Cul-port, Kochi city, Kochi

【Cover photos】
(Left) International Joint Workshop on Slow-to-Fast Earthquakes 2024
(Upper right) Field trip in Nobeoka
(Lower right) Self-invited workshop on SF Earthquakes Science in Mexico

Grant-in-Aid for Transformative Research Areas (A)
SCIENCE OF SLOW TO FAST EARTHQUAKES
Newsletter Vol.4
Date of issue 2025 March
https://en.slow-to-fast-eq.org