Slow-to-Fast Earthquake Workshop in Chile

Venue:Auditorium Enrique d'Etigny, Santiago Chile

Oral Presentations

Day1 Jan 13th

ID	Time				
0	9:00	9:20	Openning & Self-introduction		
O01	9:20	9:40	Sergio RUIZ	University of Chile	Earthquakes in Latin America (slow and fast)
O02	9:40	10:00	Ketzallina Flores	Kyoto University	Study of scaled energy: Mexico, Central America and South America
O03	10:00	10:20	Kellen Azua	University of Chile	Shallow Tectonic Tremors reveal the beginning of Slab Windows at the Chilean Triple Junction
O04	10:20	10:40	Leoncio CABRERA	Pontificia Universidad Cató lica de Chile	Immediate Foreshock or Seismic Nucleation Phase? The case of the Mw 6.9 Valparaiso (Chile) Earthquake
Break	10:40	11:00			
O05	11:00	11:20	Thorsten W. BECKER	Jackson School of Geosciences, UT Austin	Deep lithospheric rupture and mechanism transition during the July 19, 2024 Mw 7.4 Chile intermediate depth earthquake
O06	11:20	11:40	María Constanza Flores	University of Chile	Hunting for seismic swarms: insights from Norte Chico region
O07	11:40	12:00	Satoshi Ide	The University of Tokyo	Slow and Fast Earthquakes and Earthquake Models
O08	12:00	12:20	David Schmidt	University of Washington	Along-strike Changes in ETS Behavior Near the Slab Edge of Southern Cascadia
Lunch	12:40	14:30			
O09	14:30	14:50	Songqiao Shawn WEI	Michigan State University	Deep learning for subduction zone earthquakes: Insights from OBS observations in Tonga and Alaska
O10	14:50	15:10	Geoff Abers	Cornell University	Imaging the extent of the Alaska seismogenic megathrust
Poster	15:10	16:10			
O11	16:10	16:30	Kurama OKUBO	NIED	Non-self-similar scaling of laboratory earthquakes and their source mechanisms: recent progress with M-7 events
O12	16:30	16:50	Zhu-Yuan Lin	Osaka University	Stick-Slip Motion in Confined Model Smectite Clay
O13	16:50	17:10	Alexis SÁEZ	Caltech	Slow-slip events as a fluid-driven shear rupture process
O14	17:10	17:30	Diego Molina	University of Grenoble Alpes	Slip modes along a structurally-driven earthquake barrier in Chile

Day2 Jan 14th

O15	9:00	9:20	Meng (Matt) WEI	University of Rhode Island, United States	Numerical simulation of slow and fast earthquakes in Northern Chilean Subduction Zone (latitude 27S) in the framework of rate-and-state friction
O16	9:20	9:40	Ryoko NAKATA	The University of Tokyo	Triggering of large earthquakes using multiscale circular patch model in quasi-dynamic numerical simulation of earthquake generation cycle
O17	9:40	10:00	Takanori MATSUZAWA	National Research Institute for Earth Science and Disaster Resilience	Numerical modeling of the sequence of megathrust earthquakes on the Philippine Sea plate in the Kanto region
O18	10:00	10:20	Shoichi YOSHIOKA	Kobe University	3D thermal structural and dehydration modeling in the southern Chile subduction zone and its relationship to interplate earthquakes and the volcanic chain
Break	10:20	10:40			
O19	10:40	11:00	Erik Fredrickson	University of Texas Institute for Geophysics	Searching for secular vertical strain signal in the Hikurangi margin using calibrated seafloor pressure data
O20	11:00	11:20	Cristian Garcia	GFZ German Research Centre for Geosciences, Potsdam, Germany	The impact of GNSS processing strategy on the appearance of tectonic transients: A case study in the Cascadia subduction zone
O21	11:20	11:40	Anne SOCQUET	University Grenoble Alpes	Seismicity and loading on the South Peru megathrust : first results of the DEEPtrigger project
O22	11:40	12:00	Yoshihiro ITO	Kyoto University	Linking Residual Gravity Anomalies to Slow and Fast Seismic Activity in the Guerrero Seismic Gap
Lunch	12:00	14:00			
O23	14:00	14:20	Yuji ITOH	ERI, Univ. Tokyo	Largest Aftershock Nucleation Driven by Afterslip During the 2014 Iquique Sequence
O24	14:20	14:40	Francisco Ortega-Culaciati	University of Chile, FCFM, Department of Geophysics	A MUltiscale Sparse Estimation (MUSE) Approach for Quasi-Static Slip Inversion
O25	14:40	15:00	Javier OJEDA	Universidad de Chile & Université Paris Cité	Tracking the Aseismic Slip History Along the Chilean Subduction Zone (18°S-40°S): GPS Observations from 2006 to 2024
O26	15:00	15:20	Baez J.C	Universidad de Chile	Slow Earthquake recurrences And Interactions in Chile
Break	15:20	15:40			
O27	15:40	16:00	Jonathan Bedford	Ruhr University Bochum, Germany	A comparison of tectonic transients from different GNSS displacement time series solutions in Japan
O28	16:00	16:20	Helen Janiszewski	University of Hawai'i at Mānoa	Noise on Ocean Bottom Seismometers: Observations, New Directions, and Relevance for Subduction Earthquake Research
O29	16:20	16:40	Hiroyuki MATSUMOTO	JAMSTEC	Tsunamis observed by a fiber optic strainmeter
O30	16:40	17:00	Manuel J. AGUILAR-VELAZQUEZ	The University of Tokyo	Frequency and Non-Frequency Dependent DAS Strain-Rate Scaling Relations for Earthquakes Recorded in Mexico City
O31	17:00	17:20	Andrés Tassara	Universidad de Concepción	Thermal structure of the Chilean megathrust and its role on slow-to-fast earthquakes

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Poster Presentations

ID			
P1	Jared T. Bryan	Massachusetts Institute of Technology	Single-station detection and location of tectonic tremor in Cascadia
P2	Gaspard Farge	UC Santa Cruz	The Big Impact of Small Quakes on Tectonic Tremor Synchronization
P3	Hiroko SUGIOKA	Kobe University	Seismic Image of the Central to Southern Andean Subduction Zone Through Finite-Frequency Tomography
P4	Diego Molina-Ormazabal	Univ. Grenoble Alpes	Spatio-temporal evolution of earthquake potential constrained by a physical and statistical approach
P5	Naofumi Aso	Tokyo University of Science	True B-Value Estimator Based on Recurrent Neural Network
P6	Hugo REVENEAU	Institut de physique du globe de Paris	Photogeodesy : GNSS, Acoustic and Photogrammetric fusion for underwater centimetric positioning
P7	Francisco Ortega-Culaciati	Dept. of Geophysics, FCFM, Univ. of Chile	JUMPy: Automatic Characterization of GNSS Time Series Offsets (Jumps) Using Machine Learning and Bayesian Evidence
P8	Nathalie Chavarria	Georgia Institute of Technology	Resolving Near-Trench Interseismic Deformation: Evaluating GNSS-Acoustic Capabilities
P9	Keisuke Ariyoshi	JAMSTEC	Physical Mechanisms Behind an Unusually Long-Duration Slow Slip Event in the Nankai Trough

Earthquakes in Latin America (slow and fast)

Sergio Ruiz[1], Satoshi Ide[2], Bertrand Potin[1], Raúl Madariaga[1]

[1]Dept. of Geophysics, Univ. de Chile
[2]Dept. EPS, Univ. Tokyo

In the Latin America (LA) subduction zone occurs giant (≥ Mw 9.0), mega (9.0 > Mw ≥ 8.5) and large (8.5 >Mw ≥ 7.5) earthquakes and interaction between these events is not yet fully understood. Different zones have hosted earthquakes of magnitudes larger than M 8.5, which repeat every several centuries. The rupture zones that have hosted mega-earthquakes are followed for smaller events after around 3 centuries. Events around M 8.0 are more frequent, some co-located earthquakes have occurred with differences of some decades, which allows comparing his rupture using old paper seismograms and modern records. We have less understanding of the earthquakes that occurred in the oceanic plates, which have not been correctly recorded due to poor seismological instrumentation and the lack of knowledge about subduction during the first half of the 20th century in LA. Finally, slow earthquakes have been observed in some parts of LA, several of them with recurrence periods of a few years, as well as other slow seismic manifestations: tectonic tremors, low-frequency and very low frequency earthquakes. How slow and fast earthquakes are connected? This is a question that is still difficult to answer given the lack of dense geodetic and seismic networks that allow identifying all the slow earthquakes that occur in LA.

Study of scaled energy: Mexico, Central America and South America

Ketzallina Flores[1], Yoshihiro Ito[2]

[1] Graduate School of Science, Kyoto University, [2]DPRI, Kyoto University

Subduction zones are regions where one tectonic plate slides beneath another. This phenomenon generates a variety of earthquakes: interplate, tsunami, intraplate, and deep earthquakes. The different types of subduction zone earthquakes exhibit variations in the frequency content of the seismic energy released (Venkataraman and Kanamori, 2004). For example, tsunami earthquakes (Kanamori, 1972) occur in the shallow portions of the subduction zone. They are deficient in high-frequency energy; however, they have a significant amount of slip than ordynary subduction zone earthquakes. Despite their seismological similarities, there is currently no commonly accepted model that describes the structural or morphological conditions around these faults that are conducive to large tsunamis with little ground motion (Sallares and Ranero, 2019). Newman and Okal (1998) demonstrated that the scaled energy calculated from observed waveforms is one of the most powerful discriminants for tsunami earthquakes. Tsunami earthquakes typically show scaled energy values ranging from to (Venkataraman and Kanamori, 2004).

The seismic moment and the radiated seismic energy are among the most fundamental macroscopic parameters for understanding the physical processes of earthquake sources. Seismic energy reflects the dynamic characteristics of the earthquake source, while seismic moment captures the static characteristics. The ratio of seismic energy to seismic moment, or scaled energy, can be interpreted as the radiated energy per unit area and per unit slip on the fault plane (Izutani and Kanamori, 2001).

We estimate the radiated seismic energy from teleseismic P-waves using the methodology proposed by Perez-Campos et al. (2003). We calculated the scaled energy of events close to the subduction zones in Mexico, Central America, and South America. The highest scaled energy value corresponds to a normal earthquake M_W6.6 off the coast of Chile at 15 km depth (April 9th, 2001). The lowest scaled energy value corresponds to an event M_W6.7 (March 3rd, 1996) in Central America close to the Nicaragua event of 1992. Many strike-slip earthquakes have high energy while thrust events have low values.

Shallow Tectonic Tremors reveal the beginning of Slab Windows at the Chilean Triple Junction

K. Azúa[1], S. Ide[2], S. Yano[2], S. Ruiz[1], H. Sugioka[3], H. Shiobara[4], A. Ito[5], M. Miller[6], H. Iwamori [4]

[1]Dept. Geophysics, Univ. Chile, [2]Dept. EPS, Univ. Tokyo, [3]KOBEC, Kobe Univ., [4]ERI, Univ. Tokyo, [5]JAMSTEC, Univ. Tokyo, [6]Dept. Geophysics, Univ. Concepción.

The subduction of active spreading centers is an unusual phenomenon along subduction zones. In southern Chile, the Nazca-Antarctic spreading system (Chile Rise) subducts beneath the South American plate at the Chile Triple Junction (CTJ), forming the Patagonian slab window. The beginning of the slab window has been estimated based on plate kinematic reconstructions, but direct observations remain insufficient. To study this tectonic feature in detail, an Ocean Bottom Seismometer (OBS) array was deployed south of the CTJ between 2019 and 2021, and many earthquakes were detected and located around the CTJ (Ito et al., 2023). Using these continuous data and the envelope correlation method (Mizuno and Ide, 2019; Yano and Ide, 2024), we searched for tectonic tremors to complement the seismic observations and detected more than 500 events in this period. The tremors detected are mainly located beneath the Taitao Ridge, where no fast earthquakes were observed. The tremors exhibit burst and episodic activity, reaching depths less than 20 km. A notable separation between fast seismicity and tremors is observed at the current location of the subducted Chile Rise segment. We interpret this seismic gap as evidence of the Patagonian slab window formation within the last 0.3 Myr. The shallow tremor activity is likely triggered by the migration of fluids, introduced by the subduction of the spreading ridge, into the accretionary prism preserved along the Taitao Ridge.

Immediate Foreshock or Seismic Nucleation Phase? The case of the Mw 6.9 Valparaiso (Chile) Earthquake

Leoncio Cabrera[1], Sergio Ruiz[2], Piero Poli[3], Daniel Ceroni[2], Henry Montecino[4], Jesús Piña[5], Emmanuel Caballero[6], Hugo Sánchez-Reyes[7]

[1]Deptartamento de Ingeniería Estructural y Geotécnica, Pontificia Universidad Católica de Chile
[2]Departamento de Geofísica, Universidad de Chile
[3]Department of Geoscience, University of Padova, Italy
[4]Departamento de Cs. Geodésicas y Geomática, Universidad de Concepción, Chile
[5]ISTerre, Université Grenoble Alpes, France

Understanding the physical processes and conditions that lead to the initiation of an earthquake is one of the major challenges in Earth Science, with strong implications for earthquake forecast and risk assessment. Therefore, it is crucial to detect and study signals that allow us to relate the rupture of an earthquake to precursory physical processes, if any exist. Two of the main types of precursory seismological observations are foreshocks (i.e., small events that sometimes precede a mainshock) and the seismic signals related to the initial part of the mainshock waveform, often known as the seismic nucleation phase or rupture initiation. Although the latter signal has been observed before some earthquakes, it is not yet clear whether this signal corresponds to the initiation of a mainshock or simply to the rupture of another sub-event or foreshock that is not distinguishable. In this work, we report the existence of a low amplitude signal (~3.5 s) preceding the Mw 6.9 2017 Valparaiso earthquake in Central Chile, which is recorded in more than 20 strong motions stations located in the near-field. Thanks to the high sampling rate and proximity of the stations, we can apply different seismological techniques to discriminate in a quantitative way whether this signal corresponds to the initiation of the mainshock or to another sub event. Our results indicate that the Valparaiso earthquake was preceded by an immediate foreshock, located at the edge of the destabilization zone. The use of these techniques for the analysis of signals preceding other earthquakes could help to better understand the process seconds before the occurrence of an earthquake.

Deep lithospheric rupture and mechanism transition during the July 19, 2024 Mw 7.4 Chile intermediate depth earthquake

[1]Thorsten W. Becker, [1]Zhe Jia, [2]Wei Mao, [3]Maria Constanza Flores, [3]Sergio Ruiz, [3]Bertrand Jean-Maurice Potin, [4]Marcos Moreno, [5]Sebastian Barra, [3]Juan Carlos Baez

[1]Jackson School of Geosciences, UT Austin, [2]Caltech, [3]University of Chile, Santiago
[4]Pontificia Universidad Católica de Chile, Santiago, [5]Universidad de Concepción

The mechanism of intermediate depth earthquakes (70-300 km depth) remains enigmatic, with leading hypotheses attributing rock failure to either dehydration embrittlement or thermal runaway instabilities. Here we estimate the rupture details of the July 19, 2024 Chile Mw 7.4 intermediate depth earthquake and compare the rupture extent with the temperature environment resolved from thermo-mechanical simulations. We find that the rupture initiated likely from dehydration embrittlement within the cold slab core, but then propagated deeper, triggered various asperities, and eventually penetrated warm regions substantially beyond the serpentine dehydration isotherms. This indicates that a transition to shear thermal instability likely facilitated the second stage of the rupture. The dual mechanism transition expands potential rupture zones beyond conventional seismogenic boundaries, highlighting the importance to account for complex interactions between rupture mechanisms and slab thermal and compositional structures in hazard assessments for large intermediate-depth earthquakes.

Hunting for seismic swarms: insights from Norte Chico region

María Constanza Flores [1,2], Bertrand Potin [1,3], Sergio Ruiz [1], Diane Rivet [3]

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The discovery of slow deformation phenomena has transformed our understanding of earthquake processes, emphasizing the intricate spectrum betwexen slow and fast seismic events. Seismic swarms, defined as clusters of earthquakes without a clear mainshock, provide a unique opportunity to study the interaction between aseismic processes, such as slow slip events, and ordinary seismicity. These swarms are often associated with regions of low to intermediate seismic coupling and are influenced by geological heterogeneities or fluid dynamics at the plate interface.

In the Norte Chico region of Chile, the subduction of the Nazca Plate beneath South America is marked by bathymetric irregularities, including the Juan Fernández Ridge and Challenger Fracture Zone, which disrupt the seismic coupling and stress distribution. These heterogeneities make the region a natural laboratory for investigating the spectrum of deformation processes, from slow slip events to fast earthquakes.

This study aims to characterize seismic swarms across the Norte Chico region, utilizing data from the Centro Sismológico Nacional (CSN) and temporary seismic networks deployed by our research team. By employing deep learning techniques for seismic phase detection and event association, we investigate the temporal and spatial evolution of swarms, exploring their potential links to aseismic slip events and high fluid pressures. These insights contribute to a deeper understanding of the coupling between slow and fast earthquake processes in subduction settings, aligning with the interdisciplinary objectives of the Slow-to-Fast Earthquake Workshop.

Our findings emphasize the need to integrate geophysical and computational tools to further explore the continuum of deformation processes, promoting a more holistic approach to earthquake science and the dynamics of the Chilean subduction zone.

Slow and Fast Earthquakes and Earthquake Models

Satoshi Ide[1]

[1]Dept. EPS, Univ. Tokyo

Earthquakes have long been understood as manifestations of fault slip, with concepts such as the elastic rebound and stick-slip motion (e.g., Reid, 1911; Brace and Byerlee, 1966), but not all fault movements result in earthquakes. The discovery of slow earthquakes has challenged this view, as these phenomena can also be interpreted as elastic rebound or stick-slip events. Slow earthquakes, which include low-frequency earthquakes, tectonic tremors, and slow slip events, have been extensively observed since around 2000. They can occur with durations ranging from less than a second to several months or years, and their seismic moment rate is limited by a scaling relation (Ide et al., 2007; Ide and Beroza, 2023). This relationship suggests that various slow deformation phenomena within the Earth follow this law, and many fault slip motions occur as slow earthquakes. From a different perspective, deformation phenomena that do not follow this law are unique and can be considered as ordinary earthquakes. In other words, ordinary earthquakes are not ordinary as deformation events inside the Earth.

Despite these advancements, many existing earthquake models do not adequately represent the characteristics of ordinary earthquakes, such as rapid rupture propagation and seismic wave radiation. For example, the widely studied one-dimensional spring-block model and the Burridge and Knopoff (1967) model, while popular for reproducing the Gutenberg-Richter law, do not emit seismic waves. Additionally, quasi-dynamic earthquake cycle models using the rate-and-state friction law and radiation damping has unrealistically slow rupture propagation controlled by static energy balance. The recognition of slow earthquakes as a common phenomenon necessitates a re-evaluation of traditional earthquake models. Many models previously thought to represent earthquakes may be more suitable as models for slow earthquakes. It is now crucial to reconstruct our understanding and modeling of seismic events with realistic seismic energy radiation, taking into account the insights gained from the study of slow earthquakes.

Along-strike Changes in ETS Behavior Near the Slab Edge of Southern Cascadia

Carolyn P. Nuyen[1] and David A. Schmidt[1]

[1]Dept. ESS, Univ. Washington

Episodic tremor and slip (ETS) is well-documented along the entire length of the Cascadia subduction zone. We explore how the occurrence of ETS varies at the southernmost edge of the subduction zone, where geometric complexity and a slab window likely alter conditions along the plate interface. This work uses tremor and GNSS time series data to identify nineteen of the largest ETS events in southern Cascadia between 2016.5-2022 and document source properties for events approaching the slab edge. Distributed slip models for these events show that cumulative fault slip along the megathrust reaches a maximum near 40.5° N latitude and that large ETS events accommodate up to 85% of plate convergence at this location. However, ETS fault slip and tremor terminate near 40° N latitude, some 50 km before the southern lateral edge of the subducting plate. After considering a range of explanations, we propose that the complex geometry and progressive heating of the subducting plate modifies ETS behavior and does not allow seismic slip to occur along the plate interface in southernmost Cascadia below 35 km depth.

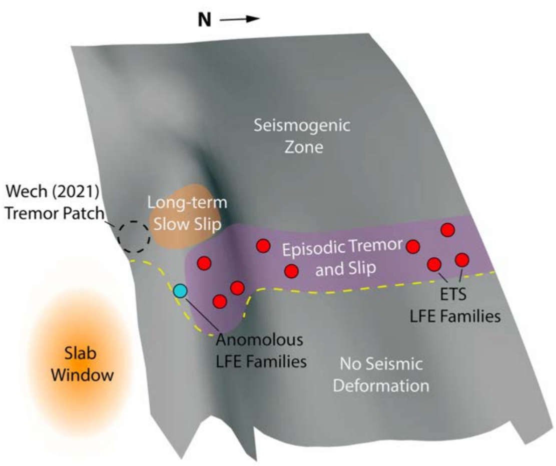

Figure caption: Schematic illustrating the distribution of deformational regimes and observed phenomena along the three-dimensional plate interface in southern-most Cascadia. The perspective is looking towards the northwest onto the warped geometry of the Gorda slab (gray surface). The dashed yellow line indicates the maximum depth at which seismic deformation occurs along the plate interface. We propose that the heating of the slab edge by an inferred slab window (orange halo to the south of the slab edge) results in the shallowing of the seismic-aseismic transition, inhibiting seismic deformation and ETS near the southernmost edge of the slab.

Deep Learning for Deep Earthquakes: Insights from OBS Observations of the Tonga Subduction Zone

Ziyi Xi[1], S. Shawn Wei[2,1], Weiqiang Zhu[3], Gregory C. Beroza[4], Yaqi Jie[2], Nooshin Saloor[2]

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[2] Department of Earth and Environmental Sciences, Michigan State University, East Lansing, Michigan, USA.

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Applications of machine learning in seismology have greatly improved our capability of detecting earthquakes in large seismic data archives. Most of these efforts have been focused on continental shallow earthquakes, but here we introduce an integrated deep-learning-based workflow to detect deep earthquakes recorded by a temporary array of ocean-bottom seismographs (OBSs) and land-based stations in the Tonga subduction zone. We develop a new phase picker, PhaseNet-TF, to detect and pick P- and S-wave arrivals in the time–frequency domain. The frequency-domain information is critical for analysing OBS data, particularly the horizontal components, because they are contaminated by signals of ocean-bottom currents and other noise sources in certain frequency bands. PhaseNet-TF shows a much better performance in picking S waves at OBSs and land stations compared to its predecessor PhaseNet. The predicted phases are associated using an improved Gaussian Mixture Model Associator GaMMA-1D and then relocated with a double-difference package teletomoDD. We further enhance the model performance with a semi-supervised learning approach by iteratively refining labelled data and retraining PhaseNet-TF. This approach effectively suppresses false picks and significantly improves the detection of small earthquakes. The new catalogue of Tonga deep earthquakes contains more than 10 times more events compared to the reference catalogue that was analysed manually. This deep-learning-enhanced catalogue reveals Tonga seismicity in unprecedented detail, and better defines the lateral extent of the double-seismic zone at intermediate depths and the location of four large deep-focus earthquakes relative to background seismicity. It also offers new potential for deciphering deep earthquake mechanisms, refining tomographic models, and understanding of subduction processes.

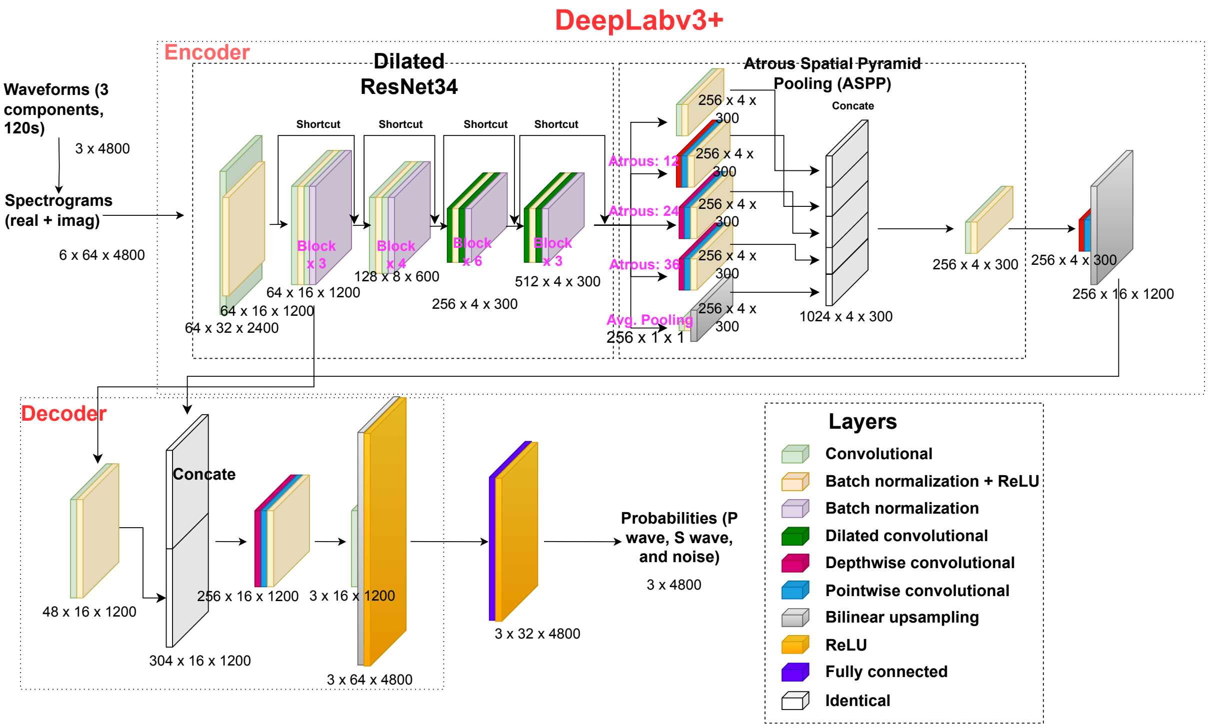

Figure 1. PhaseNet-TF architecture.

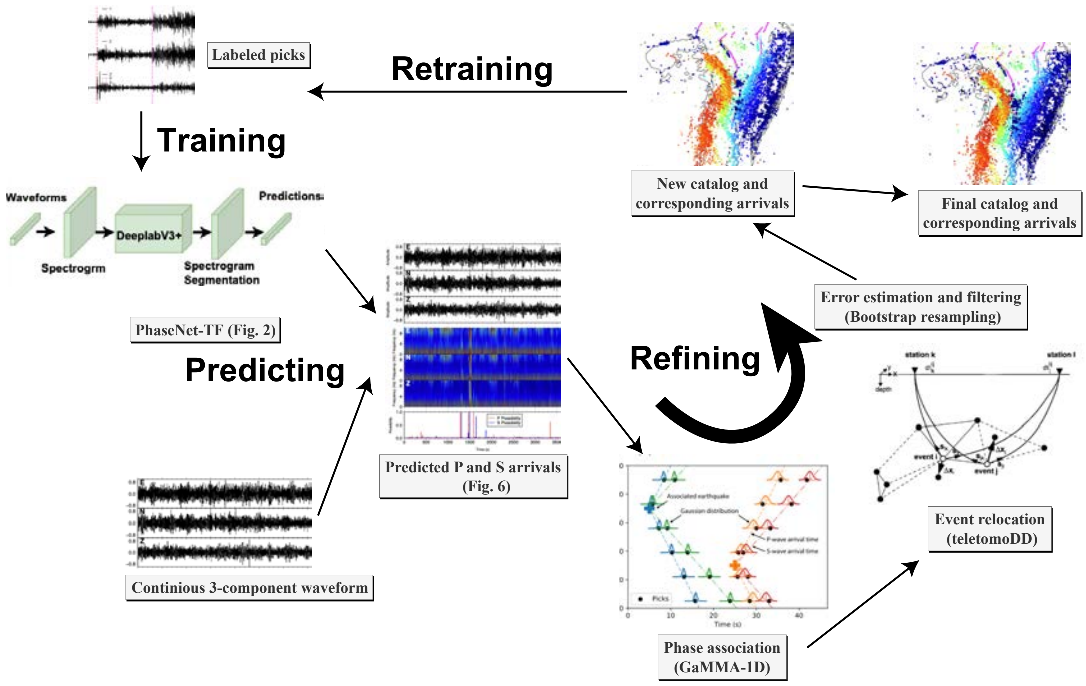

Figure 2. Schematic of our semi-supervised learning workflow.

Imaging the extent of the Alaska seismogenic megathrust

G.A. Abers[1], K.A. Daly[1,2], M.E. Mann[1,3]
(1) Cornell University; (2) University of Hawaii; (3) Brown University

The subduction megathrust slips as a seismogenic fault capable of episodic slip at all time scales, transitioning to steady ductile flow deeper. These downdip changes in rupture probably require downdip changes material properties, temperature, and fluid regime, but at depths that are difficult to sample. We have used Alaska as a testbed to compare some of the common geophysical methods for imaging the plate boundary, to understand these changes. Receiver functions show a couple km thick zone of low velocities that is contiguous throughout the locked and downdip slip region, a channel that contains the rupture zone. Careful analysis involving multiple receiver-function phases shows that the channel has Vp/Vs similar to that of many rock lithologies. High Poisson's ratios (and hence high fluid pressures) are not required by these data; lithological variations can explain the slow channel. High-frequency mode conversions from intraslab earthquakes show very large amplitudes in some parts of the plate interface but not others, varying over tens of km. This scale of lateral variability is much smaller than seen in receiver functions. Full-waveform modeling shows that many characteristics of the high-frequency mode conversions can be explained by high scattering by lenses throughout the low-velocity channel, a pattern that resembles the foliation anisotropy observed in exhumed samples. The high-frequency bright spots are good candidates for high-fluid-pressure regions. They generally lie within or just on top of the low-velocity channel imaged in receiver functions. The overall picture is of a through-going channel of deformed material hosting the megathrust, punctuated by bright spots where locally high fluid pressure. Such variability could facilitate local variations in rupture behavior.

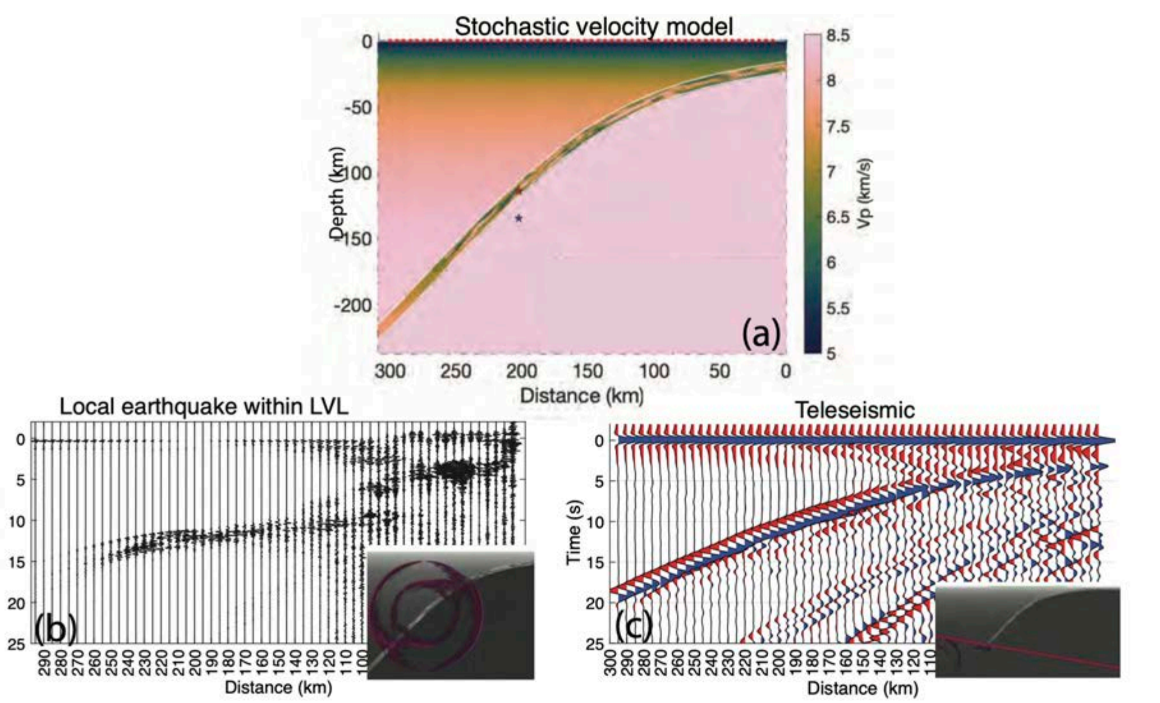

Figure: 2D full-waveform simulation of P-to-S scattering. (a) model, (b) high-frequency scattered wavefield, (c) teleseismic P coda. From Daly et al. (in prep.)

Non-self-similar scaling of laboratory earthquakes and their source mechanisms: recent progress with M-7 events

Kurama Okubo[1], Futoshi Yamashita[1], Eiichi Fukuyama[2, 1]

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[2]Graduate School of Engineering, Kyoto University, Japan

The self-similarity of the moment-duration scaling characterizes the majority of ordinary earthquakes, whereas the non-self-similarity, in which the source duration is nearly constant with the variable seismic moment, has attracted the research interest to unravel the source mechanisms deviated from the standard source models. Previous studies have shown the fixed source dimension and the various stress drops are the main factors accounting for the source characteristics of non-self-similar earthquakes. However, these mechanisms remain to be fully verified yet due to the uncertainties on the path and instrumental biases. In this study, we constrained a robust source model associated with non-self-similar earthquakes by taking advantage of the laboratory setup with the calibrated sensors and the prior constraints associated with the source geometry and the rock structure.

We used a 4-meter-long biaxial rock friction apparatus to conduct the stick-slip experiments with macroscopic normal stress of 2MPa. We located the size-controlled thin circular gouge patches with a diameter of 8 mm with spacing of 500 mm, where the gouge is made by pulverizing the same type of the host rock, metagabbro, with a median particle diameter of 8.2μm. The normal stress increased due to the topographic gap between the patch and the host rock surface, which caused the foreshocks and aftershocks promoted by the aseismic pre- and after-slip to the main stick-slip events. We obtained 44 gouge events during 56 stick slips from one of the gouge patches located 1750 mm from the edge of the fault. In order to minimize the uncertainty in the estimation associated with the source parameters, we calibrated the instrumental response of the acoustic emission (AE) sensors (V103-RM, EVIDENT; resonant frequency 1 MHz) and the attenuation structure of the rock specimen by using the laser Doppler vibrometer (Denshigiken, Melectro V100) and the ball-drop impact, respectively. We deconvolved these factors from the observed AE waveforms before analyzing the source parameters.

We estimated the seismic moment and the source duration by fitting the cosine source time function (STF) with the moment rate function obtained from the P wave displacement pulse observed with the four AE sensors installed near the gouge patch. We selected 32 out of 44 events for which all four sensors met the quality criteria based on the fitting error. The mean values of the source parameters over the four sensors per event were distributed in the range of 0.01 to 1.1 Nm (Mw -7.3 to -6.0) and 2.0 to 3.0 μs, respectively. Notably, the subset of the events showed the non-self-similar scaling such as the nearly constant duration of 2.5 μs. As the minimum estimate of the source duration, which determines the measurement limit in the experimental setup, was shorter than that of the non-self-similar subset, it is less likely to be caused by bias due to the attenuation or the instrumental response.

To develop the dynamic rupture models, we used the spectral boundary integral method-based software UGUCA (Kammer et al., 2021) with the linear slip weakening law. The initial stress

state and frictional parameters were set considering the measurements of the pressure sensitive sheet (Prescale, FUJIFILM), which was obtained before applying the shear loading, and the magnitude of the coseismic stress drop. In addition to incorporating previously reported conditions, the self-healing of the friction after a certain coseismic slip on the patch should be necessary to keep the source duration nearly constant for the case with the absence of a strong barrier around the gouge patch.

Overall, the isolated fault asperity with the different stress drops and the self-healing friction have the potential to generate non-self-similar earthquakes when the patch is loaded sufficiently to cause dynamic ruptures. These events would be useful in estimating the physical state of the natural faults.

Stick-Slip Motion in Confined Model Smectite Clay

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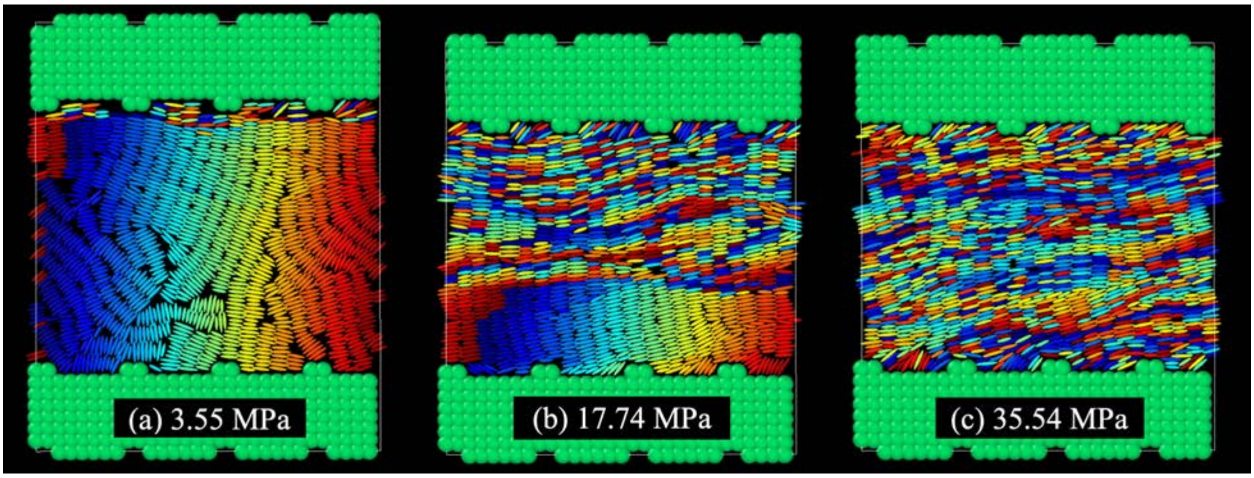
The strength and stability of shallow subduction zone is closely linked to the properties of clay-rich sediments. However, the mechanism underlying the instability remains poorly understood, as clay generally exhibits velocity-strengthening friction in laboratory settings. In this study, we performed molecular dynamics simulation on a confined model smectite clay system to examine the shear behavior at the particle level. The shape of clay particles is simplified as ellipsoids and the interactions are generalized using the Gay-Berne potential. The system displays overall rate-strengthening rheology, together with a higher static yield stress. Notably, clear stick-slip motion occurs when the system is pulled with a spring. The unstable slip is more pronounced under low normal stress with shorter duration and larger stress drop. Deformation at low normal stress is characterized by highly localized boundary shear, with the shear zone thickness increasing with normal stress. This instability at low normal stress is associated with adhesion and local structure arrangements near the upper plate. The characteristics of this instability align with recent experimental observations on wet montmorillonite. The macroscopic shear resistance of smectite clay is influenced by inter-platelet attraction at microscopic level. A decrease in salinity can lead to less attraction and contribute to strength reduction in clay-rich sediments.



Shear mode change with normal stress when the upper plate is pulled through a spring. The clay particles are colored according to their initial position before shear. (a) Boundary shear near the upper plate at 3.55 MPa. (b) The deformation zone thickness increases with normal stress. (c) Deformation pervades the whole system at 35.54 MPa.

Slow-slip events as a fluid-driven shear rupture process

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Multiple lines of evidence suggest that slow-slip events (SSE) in subduction zones occur at depths where pore fluids are inferred to be over-pressurized up to near lithostatic pressures. Moreover, a growing body of geological and geophysical observations further suggest that both the onset and arrest of SSE appeared spatially and temporally correlated with oscillations of pore pressure. Motivated by these observations, we develop a physical model in which SSE are the result of unconditionally stable frictional slip driven by pore pressure changes due to an episodic fluid source at the plate boundary. In this model, the dynamics of slow-slip transients depend strongly on the spatial-temporal characteristics of the pore pressure changes themselves. Due to limited observational constraints on pore pressure variations, we do not impose a particular fluid source but rather constrain it from observations of fault slip which are more abundant and detailed.

We determine the characteristics of the fluid source that are consistent with these observations, specifically focusing on the spatiotemporal evolution of pore pressure and injection flow rate at the fluid source. A continuum spectrum of fluid sources is obtained under the assumption that common scaling relations for SSE hold. This includes, for instance, the variation of the moment-duration scaling relation ranging from a linear to a cubic power law. We discuss what fluid sources produce SSE that propagates either at a constant rupture speed or in a decelerating manner, including the diffusional case. Such fluid sources vary from episodes characterized by sudden, violent increases in pore pressure, to cases in which the variation of fluid pressure with time is rather smooth. In any case, these episodes must be followed by a depressurization stage, which notably induces a transition from crack-like to pulse-like propagation mode –as commonly observed in kinematic slip inversions of SSE– and the final arrest of slip.

Slip modes along a structurally-driven earthquake barrier in Chile

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Abstract

Oceanic ridges often collocate with seismic barriers and episodic aseismic slip. However, how subducted seafloor topography drive interactions between slow and fast slip remains unclear. Here, using GNSS, InSAR and seismicity, we show interactions between a deep slow slip event (SSE) and a nearby shallow earthquake sequence that occurred in 2020 on northern Chile. These events overlap with the Copiapo ridge subduction, which has served as a barrier for earthquakes ruptures. Gravity field and seismic tomography reveals that the SSE nucleates in a region hosting a subducted seamount. Six months later, the seismic sequence dynamically triggers the acceleration and migration of the deep SSE, while afterslip and aftershocks propagate up to another subducted seamount at shallow depth. Our findings suggest that subducted seamounts influence fault hydromechanics, where high pore-pressure and rate strengthening material promotes continuous slip release and reduces slip deficit, processes moderated by SSEs and low magnitude seismic sequences.

Numerical simulation of slow and fast earthquakes in Northern Chilean Subduction Zone (latitude 27S) in the framework of rate-and-state friction

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Seismic and geodetic data show two zones of slow slip events near the seismic gap at latitude 27°S in the Chilean subduction zone. The two zones are at the similar latitude but different depth along the subducting plate and appear to be related to the subducting Copiapo ridge. The seismic gap separated the 1922 M8.5 earthquake to the south and the 1918 M8.0 earthquake to the north. Also, a pair of M6.5 and M6.8 earthquakes occurred in the area in 2020. Here we run quasi-dynamic numerical simulations in the framework of rate-and-state friction to study the seismic behavior of this section of the Chilean subduction zone. Particularly, we are interested in the interaction between the slow slip events and large earthquakes. First, we were able to reproduce earthquakes and slow slip events with the right size and interval. Second, we noticed that the frequency of slow slip events increased significantly right after a large earthquake. Third, the loading of nearby seismic patches creates long term (10s of years) variation in deformation signal. Four, pre-slip before large earthquakes is rare.

Triggering of large earthquakes using multiscale circular patch model in quasi-dynamic numerical simulation of earthquake generation cycle

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To understand the complex rupture process of large earthquakes, we performed quasi-dynamic numerical simulations of earthquake generation cycles based on the rate- and state-dependent friction law by adopting a multiscale circular patch model, which was used by Ide & Aochi (2013) to document the complex dynamic rupture process of the 2011 Tohoku-Oki earthquake (M9.0). For the numerical simulations, we used the same methods as those used in our previous studies (Nakata et al., 2016; 2021; 2023). In this study, instead of randomly placing unstable patches, historical earthquakes with M = 5.6 ~ 8.0 recorded by the JMA (Japan Meteorological Agency) off Sanriku area, northern segment of the Japan Trench since 1896 were used to determine the spatial heterogeneity of multiscale seismic events.

Based on Ide & Aochi (2013), we divided the historical earthquakes into four groups according to their magnitudes. Group 1 is the largest historical earthquake that occurred in 1896, the Meiji-Sanriku earthquake (M8.0). Groups 2 and 3 consist of three and nine earthquakes with Mj = 7.1 ~ 7.6 and Mj = 6.6 ~ 7.2, respectively. The fourth group originally consists of 362 earthquakes with Mj =5.6 ~ 6.5. Considering that some historical earthquakes are repeating earthquakes, we finally used a total of 41 patches for Group 4, reducing some patches. The source areas of each group of historical earthquakes were modeled as circular patches of equal size within each group. The characteristic slip distance (L) was set to be constant within each group and proportional to the patch radius. The background area without these circular patches has a large value of L. We assumed spatial heterogeneity only in L for each group. Then, A-B was set to be uniform and the velocity-weakening throughout the model domain.

As a result, approximately 12,000 earthquakes with M = 5 ~ 8 occurred in 2,600 years. Among them, 43 earthquakes of the M = 8.15 ~ 8.29 occurred with a recurrence interval of about 61 years. The centroid of the slip distribution for M > 8 earthquakes is almost at the same location for 43 events. However, the rupture initiation point for M > 8 earthquakes shows a different pattern and is almost at the same location as for M < 8 earthquakes. All of the M > 8 earthquakes showed a cascade-up rupture process originating from small size patches. The afterslip of the M ~ 6 to M < 8 earthquake (i.e., a foreshock) propagated into the surrounding area, which accelerated and triggered the rupture of the M ≥ 8 earthquake. There was also a pattern of earthquakes that initiated at almost the same location but were of different magnitudes. Some M > 8 earthquakes were triggered by slow slip.

By adopting a multiscale structure, we were able to show different triggering scenarios for M > 8 earthquakes. Our results suggest that a hierarchical structure is fundamental for simulating not only the dynamic rupture process, but also the preparation process, the propagation process, and subsequent relaxation process of long-term earthquake cycles.

Numerical modeling of the sequence of megathrust earthquakes on the Philippine Sea plate in the Kanto region

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Devastating megathrust earthquakes recur in the Kanto region, Japan, where the Philippine Sea Plate (PHS) is subducting below the inland plate. In addition, slow slip events (SSEs) repeat off the Boso Peninsula. Recently, Saito and Noda (2023) estimated stress accumulation rate on the PHS in the Kanto region using GNSS data, and suggested that the area with high stress accumulation rate can be considered as the area with large stress drop at a possible future earthquake. The stress accumulation process is thought to be controlled by the frictional property at the plate interface. In this study, we tried to reproduce the megathrust earthquakes and SSEs by the numerical simulation of frictional slip on the PHS based on their result.

To model megathrust earthquakes and SSEs, we adopt a numerical modeling similar to our previous studies (Matsuzawa et al., 2010, 2013), in which a rate- and state-dependent friction law (RS-law) with cutoff velocities is used. Based on Saito and Noda (2023), we assume negative (a-b) value in the RS-law around the region with high stress accumulation rate, while positive (a-b) value (i.e., stable sliding) is assumed in the other region. In the off-Boso SSE region, effective normal stress is set to lower value than that at the same depth to reproduce SSEs (e.g., Matsuzawa et al., 2010). The subducting PHS is modeled by about 73,000 triangular elements. Temporal evolution of slip velocity is numerically simulated, introducing elastic response of semi-infinite medium and realistic configuration of the plate interface.

In the numerical result, megathrust earthquakes and SSEs are reproduced mainly at the region with high stress accumulation rate, and have the recurrence intervals of 200-300 years and 6-7 years, respectively. These are similar to the observations (e.g., Satake, 2023; Hirose et al., 2012). Variety of slip distribution of megathrust earthquakes is found in the numerical result. For example, the slip events, which include all regions with high stress accumulation rate, repeatedly occur, and the typical magnitude is Mw8.3 and similar to the 1703 Kanto earthquake (Mw8.1-8.5 by Satake, 2023; the Genroku-type earthquake). Slip events at only the western part are also found, and the typical magnitude is Mw7.9. This is similar to the 1923 Kanto earthquake (Mw7.8-8.2 by Satake, 2023; the Taisho-type earthquake). In the result for 4000 years, two Taisho-type earthquakes are found, and occur after 220-230 years from a Genroku-type earthquake. This is similar to the sequence of the 1703 and 1923 megathrust earthquake. However, the next earthquakes (~Mw8.2) occur at the eastern part, which is similar to the Genroku-type, after ~90 years from the Taisho-type earthquakes, although such earthquakes have not occurred yet after the 1923 earthquake. In addition, for 4000 years, the number of the Genroku-type and Taisho-type events are 14 and 2, respectively. Thus, the Genroku-type earthquakes seem to be too frequent in our preliminary numerical result. Comparison with the recurrence behavior obtained from historical and prehistorical data (e.g., Satake, 2023) might make our model more realistic, and enable us to interpret the current stress accumulation data, directly.

3D thermal structural and dehydration modeling in the southern Chile subduction zone and its relationship to interplate earthquakes and the volcanic chain

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In southern Chile, the Nazca plate is subducting beneath the South American plate. This region was struck by megathrust earthquakes in 1960 and 2010 and is characterized by the existence of a volcanic chain. In this region, we modeled a three-dimensional thermal structure associated with the subduction of the Nazca plate by using numerical simulations. Based on the obtained temperature distribution, we determined the updip and downdip limit temperatures for the region ruptured by these two megathrust earthquakes. In addition, the distributions of water content and dehydration gradient were calculated by using appropriate phase diagrams and compared with the location of the volcanic chain. As a result, we infer that the coseismic slip of the 2010 Mw8.8 Maule earthquake occurred only at temperatures lower than and around the 350 °C isotherm that resembles the beginning of the brittle–ductile transition. We also deduce that the rupture of the 1960 Mw9.5 Valdivia earthquake propagated up to the 450 °C isotherm because the magnitude was considerably large and the young hot plate subducted near the Chile Ridge. In addition, the hydrous minerals in the turbidites, MORB and ultramafic rocks released fluids via dehydration reactions, and dehydrated water migrated upward almost vertically, decreasing the melting point of the mantle wedge and contributing to the formation of the volcanic chain.

Searching for secular vertical strain signal in the Hikurangi margin using calibrated seafloor pressure data

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We present a calibrated seafloor pressure dataset from the Hikurangi subduction zone. These data are from the first year of a three-year marine geodetic and seismic experiment in the region. We use the "A-0-A" calibration method to remove the instrumental drift from these observations, making them sensitive to real long-period signals. For this first year of observation, no significant slow slip deformation is thought to have occurred beneath the margin, as evidenced by coastal GNSS data, presenting an opportunity to instead observe the secular strain signal from ongoing convergence. After using a low-pass filter to remove the tides, the pressure data show linear trends ranging from -15 to +10 hPa/yr pre-drift correction, which are reduced to -3 to +7 hPa/yr after correction. The observed and corrected drift rates range from <1 to >20 hPa/yr. To separate the oceanographic and solid-Earth components from the drift-corrected pressure records, we correct with predicted pressures from the global ocean circulation models GLORYS and ECCO2. Though the models have poor coherence with the observed pressures at high frequencies, they are much better at periods greater than 30 days. These long-period, model-corrected data have much more reasonable linear trends, ranging from -1 to 5 hPa/yr, depending on which model is used. Though much smaller, these rates are still too large to be explained by secular strain alone and it is ongoing work to improve the separation of ocean and Earth signal. Additional observations from the full deployment include water column constraints, which will help in this endeavor.

The impact of GNSS processing strategy on the appearance of tectonic transients: A case study in the Cascadia subduction zone

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The detection of transient tectonic signals, defined as unexpected accelerations in the Earth's crust, is crucial for enhancing both our understanding of fault zone deformations and seismic hazard assessments. Global Navigation Satellite System (GNSS) coordinate displacement time series provide valuable insights into a range of geophysical phenomena, including linear tectonic motion, seismic displacements, post-seismic decays, and other periodic signatures such as non-tidal loading. However, as the number of GNSS stations and time series increases, the discrmination of tectonic transients from processing artifacts becomes more challenging. The objective of this study is to optimise GNSS processing workflows (see Figure 1) in order to enhance the detection of transient signals, with a particular focus on the Cascadia region.

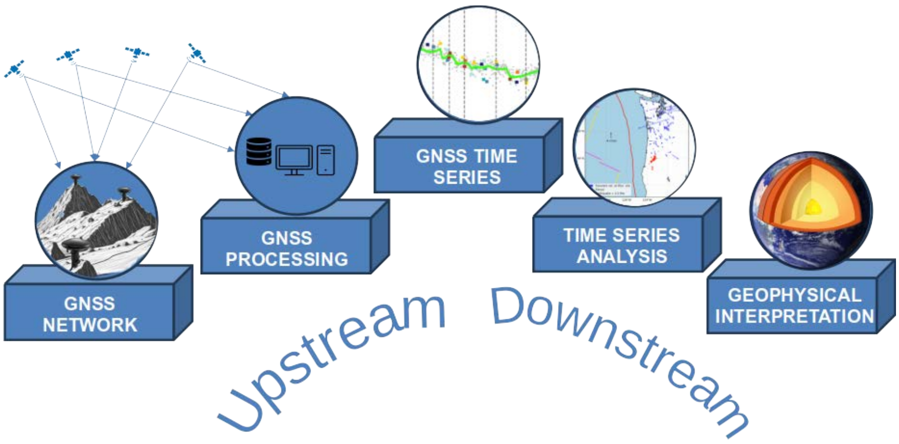

Fig. 1 Upstream and downstream operations for detection of transient signal in Tectonic-Geodesy. Include element from "Earth cutaway.png" by Charles, licensed under [CC BY-SA 3.0] (https://creativecommons.org/licenses/by-sa/3.0/)

GNSS data from 189 stations were subjected to analysis, including 66 reference stations from the International GNSS Service (IGS) and monitoring stations across Cascadia, spanning the period from 2015 to 2019. Four distinct network-based GNSS processing approaches were tested, utilising ambiguity fixing as outlined by Ge et al. (2005) without orbit determination, in alignment with the IGS repro3 settings. The Greedy Automatic Signal Decomposition (GrAtSiD) (Bedford and Bevis, 2018), was applied to the data, using a modified extended trajectory model (ETM) that incorporates linear, seasonal, step, and decay basis functions. Hyperparameters were optimized to avoid over-/under-fitting of the time series.

The preliminary results indicate that a regional alignment (i.e., No-Net-Rotation and No-Net-Translation) produces greater number of transient events in comparison to a global solution, with the global solutions having a 30% higher noise level. It is postulated that this is likely due to Geocenter motion. Our findings indicate that regional datum solutions, despite using fewer reference stations, are better suited for detecting transients in the Cascadia region. However, distinguishing true tectonic events from technological artifacts requires detailed analysis of GNSS data quality. Future work will include comparing detected transients with seismic tremor catalogs to further validate the findings.

This research contributes to the growing ability to recognize transient tectonic signals and refine methodologies for distinguishing between artifacts and true tectonic phenomena, thereby enhancing our understanding of crustal deformation in active fault zones.

Seismicity and loading on the South Peru megathrust : first results of the DEEPtrigger project

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The south Peru subduction is known to host large megathrust earthquakes, such as the 2001 Mw8.3 Arequipa earthquake. However, our knowledge of the interseismic loading and release on this subduction zone is limited because geophysical observations were sparse so far. Here we show the first results of a series of GPS measurements together with a seismological deployment over 2022-2024. Seismic tomography from full waveform inversion together with a dense seismicity catalogue constructed using machine learning techniques provides us with a refined geometry of the South Peru subduction zone, highlighting the transition between the the flat slab area caused by the subduction of the Nazca ridge to a strongly dipping slab in the south. Viscoelastic models accounting for the interseismic coupling and the post-seismic relaxation, that is still ongoing after the 2001 Arequipa earthquake, provide estimates of the seismic potential on the megathrust. Seismicity together the interseismic coupling show a nice complementarity and design the segmentation along the megathrust, with a low coupling associated with shallow seismicity in the area of the Nazca ridge, and a strong coupling with a gap of seismicity in the southern segment. The seismicity seems to be strongly correlated with the extend of structures in the slab. Interestingly, the area of transition between the flat to the strongly dipping slab hosts repeated Mw ~7 earthquakes in 2023, 2018 and 2024. Our network was able to capture the Mw7.2 June 28th Acari earthquake as well as its foreshock aftershock sequence that shows intriguing patterns very deep into the slab. All these results are ongoing but interesting work, and I wanted to share this in the frame of this workshop.

Linking Residual Gravity Anomalies to Slow and Fast Seismic Activity in the Guerrero Seismic Gap

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The characteristics of the overriding plate play a crucial role in the occurrence of both slow and fast earthquakes. Notably, within the shallow regions of subducting margins, the material atop the plate interface—especially within an accretionary wedge—may be compromised by the subduction of seamounts beneath it. Recent numerical simulations, such as those by Sun et al. (2020), suggest that variations in the physical properties of the accretionary wedge are vital for controlling slip behavior along the plate interface, influencing phenomena such as tectonic tremors, slow slip events, tsunami earthquakes, and fast earthquakes. The Guerrero seismic gap, having recorded no megathrust earthquakes in the last century, is a valuable study case for examining the relationship between the physical properties of the accretionary wedge and the occurrence of slow-to-fast earthquakes. Despite the absence of megathrust events, the Guerrero seismic gap has experienced various modes of slip at shallow depths near the trench. These include episodic shallow tremors, possible slow slip events, and the 2002 Mw 6.7 earthquake, which has a prolonged source time function exceeding 90 seconds and emitted relatively low seismic energy, similar to tsunami earthquakes. The tectonic tremors and the 2002 tsunami earthquake occurred near the trench, within an area of a positive residual gravity anomaly of about 50 mGal. The slip distribution of the 2002 tsunami earthquake aligns with this gravity anomaly, with the tectonic tremors clustered around them. This suggests a linkage to subducting seamounts as inferred from bathymetric data. The 2002 tsunami event likely occurred beneath a damaged or low-rigidity accretionary wedge situated above a subducting seamount. In contrast, the downdip portion of the high residual gravity anomaly zone shows an extremely low residual anomaly of around -50 mGal, covering a significant part of the Guerrero seismic gap. This area, characterized by a negative residual anomaly, exhibits minimal seismic activity, encompassing both slow and fast earthquakes. The presence of this negative residual anomaly may indicate increased porosity within the accretionary wedge, potentially resulting from the subducting seamount.

Largest Aftershock Nucleation Driven by Afterslip During the 2014 Iquique Sequence

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Various earthquake models predict that aseismic slip modulates the seismic rupture process but actual observations of such seismic-aseismic interaction are scarce. We analyze seismic and aseismic processes during the 2014 Iquique earthquake sequence. High-rate Global Positioning System displacements demonstrate that most of the early afterslip is located downdip of the M 8.1 mainshock and is accompanied by decaying aftershock activity. An intriguing secondary afterslip peak is located ∼120 km south of the mainshock epicenter. The area of this secondary afterslip peak likely acted as a barrier to the propagating mainshock rupture and delayed the M 7.6 largest aftershock, which occurred 27 hours later. Interevent seismicity in this secondary afterslip area ended with an M 6.1 near the largest aftershock epicenter, kicking the largest aftershock rupture in the same area. Hence, the interevent afterslip likely promoted the largest aftershock nucleation by destabilizing its source area, favoring a rate-dependent cascade-up model.

Published work:
Itoh, Y., Socquet, A., & Radiguet, M. (2023). Largest aftershock nucleation driven by afterslip during the 2014 Iquique sequence. Geophysical Research Letters, 50, e2023GL104852. https://doi.org/10.1029/2023GL104852

A MUltiscale Sparse Estimation (MUSE) Approach for Quasi-Static Slip Inversion

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Seismic cycle fault processes produce deformation signals on the surface of the Earth that can be measured with space geodetic instruments, such as GNSS and InSAR. Robustly imaging the causative fault slip throughout the seismic cycle is crucial for improving our understanding of the generation of large earthquakes and for enhancing seismic and tsunami hazard assessments. Slip estimation is an ill-posed inverse problem that can be approached using Bayesian sampling or regularized optimization methods, for instance. We focus our efforts on improving inversion methods driven by optimization techniques, as these are more suited when fast solutions are required or for solving large problems where the number of model parameters defies the feasibility of sampling methods.

We propose a novel methodology based on sparsity-inducing estimation techniques, that infers quasi-static slip accounting for the spatial variability of the constraints posed by surface observations. We define a multiscale representation of the slip distribution at a non-planar fault, as the linear combination of a redundant dictionary of functions (e.g., B-splines), with different levels of complexity, defined over the fault. The proposed methodology then uses surface data to infer a slip distribution that employs a minimal number of functions selected from the dictionary. Following the principle of parsimony, the methodology infers slip with the minimum complexity required by the data, accounting for the spatially variable constraints on slip provided by surface observations. We assess the effectiveness and limitations of the methodology through experiments with noisy synthetic data generated from various slip distribution scenarios. We apply the proposed methodology to estimate the slip distribution of large subduction earthquakes, such as the Japan 2011 (M_w 9.0) Tohoku-oki or Chile 2015 (M_w 8.3) Illapel, constrained by geodetic observations, and compare our findings with those of previous studies.

Tracking the Aseismic Slip History Along the Chilean Subduction Zone (18°S-40°S): GPS Observations from 2006 to 2024

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Chile, with its over 3,000 kilometers of active subduction along the Nazca-South America plate boundary, serves as a natural laboratory for studying various seismic and aseismic slip phenomena at the plate interface. In this work, we systematically trace the history of aseismic short-term transient deformation along the Chilean subduction zone by analyzing over 18 years of daily GPS data (period 2006 - 2024) that continuously recorded the crustal deformation from 18°S to 40°S. To achieve this, we first derive daily velocities from GPS time series and then sequentially invert these velocities to estimate daily slip and moment release along the plate interface. This method successfully captures the preparatory phase leading up to the Mw 8.1 2014 Iquique earthquake and its subsequent afterslip. Our findings reveal that (1) Most large earthquakes (M>6.5) induce transient deformation during their afterslip phases; (2) specific, well-monitored seismic clusters correlate with episodes of transient moment release; and (3) some transient events occur independently of microseismicity, pointing to additional signatures of slow slip. We also identify two new segments, in Copiapó and Los Vilos, that likely host shallow and short-term slow slip events (<40 km depth). Lastly, our results highlight the critical need for optimized GPS network design and offshore measurements to improve the current network's detection limits.

Slow Earthquake recurrences And Interactions in Chile

Báez J.C., Ruiz S., Moreno M., Leyton F., Barra S.

Abstract

Anomalous surface motions not associated with traditional earthquakes are increasingly being observed through space geodetic data (GNSS and InSAR) and seismology. Transient deformation, manifested as deviations from steady motion, can indicate slow aseismic energy release, commonly referred to as slow slip events (SSEs). These SSEs, along with seismic swarms, may precede larger earthquakes and can be considered precursory activity. Some of these events correlate with repeaters, non-volcanic tremor (NVT), and low frequency earthquakes (LFE); however, SSEs are not always associated with these phenomena. The nature of SSEs remains not fully understood, as their identification is challenging due to their overlap with other (typically larger) tectonic signals, hydrological loading effects, and general noise. This complexity require sophisticated signal processing techniques for robust detection. In this study, we process and analyze the largest available set of GNSS and seismic data along the Chilean subduction zone to characterize transient events. This effort allows us to compile a database of nearly two decades of observations covering segments of the margin in various phases of the seismic cycle, including areas in the late seismic and early and late post seismic periods. We have made special efforts to monitor the main seismic gaps in Chile, conducting geodetic and seismological experiments to increase the density of continuous monitoring stations. We identified transients of varying magnitudes and durations, some occurring before major earthquakes and others in the post-earthquake period. We present an overview of the characteristics of the main SSEs detected and compare our new results with previous studies and the occurrence of recent earthquakes in Chile. Finally, integrating our findings with mechanical modeling will provide new insights into the role of SSEs in the seismic cycle of large earthquakes and the physics governing their occurrence.

A comparison of tectonic transients from different GNSS displacement time series solutions in Japan

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There are now many published studies investigating the spatiotemporal features of Japan's surface displacements as captured by GNSS. Due to different processing and time series analysis strategies, there is ongoing debate about which signals are of a tectonic origin and which ones are occurring due to processing artifacts. Here I present the time series analysis from a selection of published GNSS displacement time series. I demonstrate a new approach to the noise reduction of network solutions, present the daily repeatabilities before and after noise reduction, and propose a new approach for visualizing daily velocities obtained from trajectory models. In particular, I compare the trajectory models of the different displacement time series solutions to known (published) tectonic transients, some of which have accompanying seismic evidence. Finally, I suggest reasons why the features we see in different time series differ, and give an update on the ongoing work of the ERC TectoVision project into improving processing strategies for the detection of tectonic transients in GNSS data.

Noise on Ocean Bottom Seismometers: Observations, New Directions, and Relevance for Subduction Earthquake Research

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The proliferation of broadband ocean bottom seismometer (BBOBS) deployments has generated key datasets from diverse marine environments, improving our understanding of otherwise inaccessible ocean basin structure and evolution as well as tectonic and earthquake processes occurring at the plate boundaries. Recent development of community software has made these datasets more accessible and, in turn, the community of scientists using this data has expanded. This growth in BBOBS data collection is likely to persist with the arrival of new seismic seafloor technologies and continued scientific interest in marine and amphibious (shoreline crossing) targets. In particular, such deployments are a key aspect of research related to subduction megathrust structure and earthquake processes. However, the noise inherent in BBOBS data poses a challenge that is markedly different from that of terrestrial data. Sources of noise on the seafloor, the degree to which they couple to the seismometer housing, and their variation with seafloor environment are often not well understood. Here, we compute global trends in BBOBS noise (e.g., impact of water depth and seismometer type on compliance and tilt noise), and use these observations to motivate more detailed investigations of novel instrumentation and methodologies for noise characterization and removal. This includes the utility of denoising techniques for improving ambient-noise-based imaging, comparisons of temporary broadband OBS data with permanent cabled instrumentation, and exploration of non-traditional (e.g. machine learning based) noise removal strategies. We include a discussion related to results from recent deployments at subduction zone settings.

Tsunamis observed by a fiber optic strainmeter

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Advances in fiber optic sensing technology have made it possible to detect vibrations, temperature changes and other phenomena on optical fibers with high accuracy. For example, fiber optic sensing technologies such as Distributed Acoustic Sensing (DAS), which measures the phase differences of Rayleigh scattered waves along the entire optical fiber, have widely used in seismology. Fiber optic sensing is also highly sustainable, as observations can be performed using only the optic fiber without the power supply. As a result, it is being applied in the field of geosciences, for example, to observe ground motions to monitor seismic activity and volcanoes, predict landslide, and understand marine ecosystem.

The Japa Agency for Marine-Earth Science and Technology (JAMSTEC) has started to observe crustal deformation of the seafloor in the Nankai Trough by using a fiber optic strainmeter. A 200-m long fiber optic strainmeter was installed on the seafloor by an underwater Remotely Operated Vehicle (ROV) for the first time in 2019 (Araki et al., 2019). Two fiber optic strainmeters were additionally installed at the same location with different directions in 2022. These fiber optic strainmeters are connected to the DONET seafloor network, and the in-situ dataset is available in real-time. The present study introduces that the tsunami detections originating from the episodic events near Torishima Island by a fiber optic strainmeter from the point of view of surveillance of submarine volcanic eruptions.

A series of submarine earthquakes near Torishima, a volcanic island of the Izu-Ogasawara (Izu-Bonin) Islands, Japan started in early October 2023 (Figure 1). Numerous small earthquakes occurred from around 19:00 UTC to around 21:30 UTC on 08 October near the island. The Japan Meteorological Agency (JMA) issued a tsunami advisory for the Izu-Ogasawara Islands after observing a tsunami on one of the islands, although the magnitude of the earthquake remained unknown. During this episodic event, three seafloor fiber optic strainmeters deployed in the Nankai Trough recorded 14 significant hydroacoustic signals, followed by a dispersive tsunami wave (Figure 2(a)). The two micro-strain amplitudes were measured at 0.07~0.2 εμ and 0.003 εμ, respectively. On the other hand, the closer DONET pressure gauge, located approximately 3 km away, observed 1~5 hPa hydroacoustic signals and a 1.4 hPa tsunami wave. The spectrogram shows that the identified 14 hydroacoustic signals have short duration and broadband frequency contents, suggesting that the hydroacoustic signals may be associated with underwater explosive events. The main features of the frequency contents, i.e., short duration and broadband observed on the seafloor fiber optic strainmeters are comparable with the DONET sensors.

In the meantime, another submarine earthquake with magnitude of 5.8 occurred at about 110 km north of Torishima, generating a tsunami on 23 September 2024 (Figure 1). Discolored water was identified by a flyover observation 5 days before this episodic event, suggesting the submarine volcanic activities were getting high. The frequency contents of the first arrival packet are similar to the 2023 event, while its duration was relatively large, suggesting the seismic wave was dominated more than the hydroacoustic waves. Following the seismic waves, a dispersive tsunami wave could be identified on the fiber optic strainmeter from 00:00 UTC on 24 September 2024 (Figure 2(b)). The amplitude of the observed tsunami wave was less than 0.05 nε. Further examinations is needed to quantify the phase by comparing the DONET pressure sensor.

Although discrimination between pressure contribution and seafloor deformation to the strain change should be discussed, what the tsunami observation by the seafloor fiber optic strainmeters suggests that fiber optic sensing technologies can detect long-period phenomena such as slow slip events (SSEs).

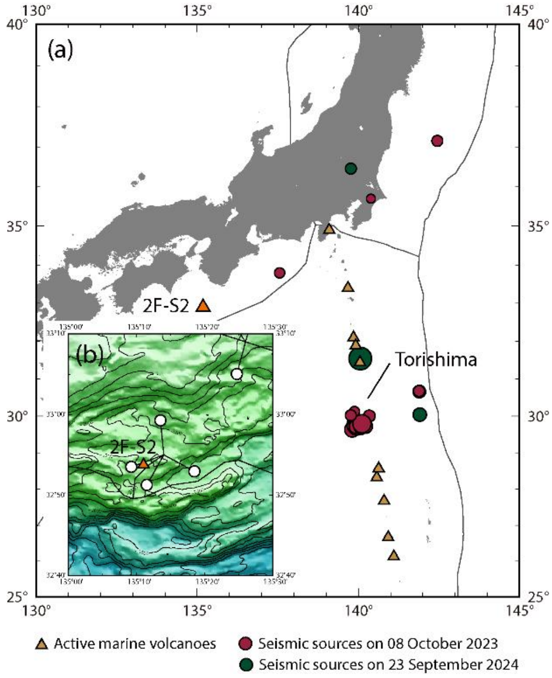

Figure 1. (a) Map showing the study area. Red and green circles represent the seismic sources determined by the USGS on 08 October 2023 and 23 September 2024, respectively. (b) Detailed map showing 2F-S2 site denoted by the orange triangle, where three fiber optic strainmeters are installed. Open circles represent the DONET stations.

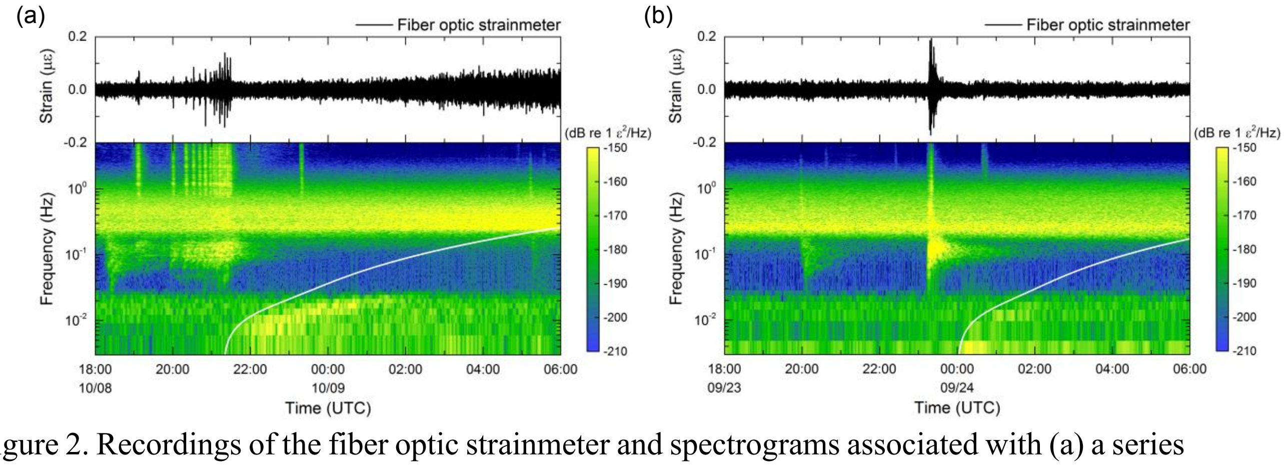

Figure 2. Recordings of the fiber optic strainmeter and spectrograms associated with (a) a series of submarine earthquakes on 08 October 2023 and (b) an earthquake on 23 September 2024. Chirp curves represent the theoretical tsunami arrival times.

Frequency and Non-Frequency Dependent DAS Strain-Rate Scaling Relations for Earthquakes Recorded in Mexico City

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Distributed Acoustic Sensing (DAS) has gained popularity in the seismological research community for its capacity to provide high-resolution spatially distributed (strain/strain-rate) seismic records. One of the applications of DAS has been the earthquake magnitude retrieving using either P- or S-wave records (i.e., scaling relations). In this work, we present DAS scaling relations for earthquakes recorded in Mexico City using S-wave strain-rate records. Two approaches were implemented: 1) non-frequency dependent using earthquake magnitude, hypocentral distance (HD), and the peak RMS amplitude observed in the records, and 2) frequency-dependent relation between strain-rate spectrum, HD, and the acceleration source function in the frequency domain. Our results reveal that magnitude and geometric spreading coefficients (0.43 and -0.89, respectively) in both scaling relations are consistent with those expected according to the theory (0.5 and -1.0, respectively). Precisely, for the frequency-dependent approach, only the frequency interval from 0.6 to 9.0 Hz produces reasonable results (even comparable with the non-frequency-dependent relations), which may make sense because, in this frequency band, the signal-to-noise ratio is large enough to be sure that seismic signals were reliably recorded. Finally, we compare S-wave strain rate and acceleration records (recorded in almost collocated seismic stations) and show how they are proportional, with the shallow S-wave velocity being the proportionality constant.

Thermal structure of the Chilean megathrust and its role on slow-to-fast earthquakes

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The nucleation and fast propagation of a seismic rupture can occur inside a restricted range of temperatures (100-400ºC) where the frictional properties of velocity-weakening faults patches allow unstable sliding. Below and above this range, slow stable sliding is predicted inside velocity-strengthening regions. Aiming to test these theoretical predictions, we implemented a simple analytical formulation of the thermal regime to compute temperatures along 4000 km of the Chilean megathrust. Most of the thermal and tectonic parameters included in this formulation were considered either as constants with values selected from the literature or prescribed by their spatial variations as constrained by independent information. The only two remining unknowns are the radiogenic heat production of the upper plate A and pore fluid pressure ratio λ of the fault. Exploring this 2D parameter space, we show that models minimizing the Root Mean Square Error (RMSE) between predicted surface heat flow Q_0 and observations lie along a line of positive slope. This is expected because, for a given value of Q_0, an increase of radiogenic heat must be compensated by an increase of λ to reduce frictional heating. We divided our analysis between northern (18°-33°S) and southern (33°-45°S) megathrust segments owing to differences in the geological context and availability of Q_0 estimates. For each segment, we selected our preferred model (i.e., the optimal combination of A and λ) between models of minimum RMSE by comparing the location of the 350°C isotherm (the theoretical downdip limit (DDL) of the seismogenic zone) with DDL estimates based on seismic and geodetic constraints. We found that λ lies in a very restricted range of 0.90+-0.01 along the entire margin but A is significantly larger in the south (4-4.5 mW/m^3) than in the north (2.5-3 mW/m^3). These findings have relevant implications regarding the geological structure of the forearc and subduction channel and its control on the hydraulic and thermal state of the megathrust. We used our preferred models to show that aprox. 85% of earthquakes recorded by the Chilean seismic network between 2000 and 2024 have hypocenters at temperatures between 125°C and 350°C. The pick in the number of events and their magnitudes occur at 200-300°C, and we note a rather gradual decrease in the number of events with increasing temperature above this range. This is also true for the amount of coseismic slip of great Mw>8 earthquakes. A remining task, that we want to develop and present in this workshop, is to analyze the spatial correlation of temperature with the location of the few slow slip events that have been recorded along the Chilean margin. This will help understanding the role of temperature in the transition between slow to fast earthquakes in this subduction zone and elsewhere.

Single-station detection and location of tectonic tremor in Cascadia

Jared T. Bryan[1], William B. Frank (presenting author) [1], Léonard Seydoux[2], and Aaron G. Wech[3]

[1]MIT, [2] Université Paris Cité, [3]USGS

Tectonic tremor is the primary seismic signature of slow fault slip, and its spatiotemporal behavior is key to understanding the underlying physical mechanisms driving slow deformation. Tremor is thought to emerge from the superposition of many low-frequency earthquake sources, each with distinct P- and S-phases. However, tremor lacks clear seismic phases, requiring envelope-based detection and location methods that discard complex phase information and retain only coarse measures of signal energy. The utility of envelope-based tremor locations depends strongly on the density and aperture of the seismic array used to backproject the seismic energy toward a grid of potential sources. Evolving network coverage and intermittent deployment of dense networks results in slow slip events resolved with differing quality, particularly when analyzing historical datasets or regions with sparse instrumentation.

We address the evolving tremor detection capacity of seismic arrays by training a convolutional neural network to map continuous waveforms from a single three-component seismic station to the tremor times and locations from the Cascadia tremor catalogs of Ide (2012) and Wech (2021). Implicitly, this approach uses the detection capacity of the full seismic network of present-day Cascadia to identify patterns in tectonic tremor not visible when viewed in isolation. Tectonic tremor is composed of repeating earthquakes whose waveforms encode a stationary seismic source and location, but the complex temporal activation of multiple such sources makes it difficult to explicitly use this information for tremor location. By directly mapping from single-station continuous seismic data to the network-constrained tremor locations, we produce a representation of the tremor that is invariant to the particular temporal activation of LFEs, encoding the Green's function between the tremor source and the seismic station. We apply this model to over 20 years of continuous seismic data in Cascadia to detect tremor sources with uniform detection capacity.

The Big Impact of Small Quakes on Tectonic Tremor Synchronization

Gaspard Farge[1], and Emily E. Brodsky [1]

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Tectonic tremor tracks the repeated slow rupture of certain major plate boundary faults. One of the most perplexing aspects about tremor is that some fault segments produce strongly periodic, spatially extensive tremor episodes, while others have more disorganized, asynchronous activity. Here we measure the size of segments that activate synchronously during tremor episodes and the relationship to regional earthquake rate on major plate boundaries. Tremor synchronization in space seems to be limited by the activity of small, nearby crustal and intraslab earthquakes. This observation can be explained by a competition between the self-synchronization of fault segments and perturbation by regional earthquakes. Our results imply previously unrecognized interactions across subduction systems, in which earthquake activity far from the fault influences whether it breaks in small or large segments.

Seismic Image of the Central to Southern Andean Subduction Zone Through Finite-Frequency Tomography

Yuko Kondo[1], Masayuki Obayashi[2,1], Hiroko Sugioka[1], Hajime Shiobara[3], Aki Ito[2], Masanao Shinohara[3], Hikaru Iwamori[3], Masataka Kinoshita[3], Matthew Miller[4], Carlos Tassara[5], Javier Ojeda[6]

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This study presents new seismic imaging of the Andean subduction zone through P-wave hybrid finite-frequency and ray-theoretical tomography. We measured both differential and absolute traveltimes using broadband seismic waveforms from stations in an array of ocean-bottom seismographs near the Chile Triple Junction (CTJ) and stations within 30° of the array. These data were combined with the global traveltime data set to obtain a global P-wave velocity structure with a focus on central to southern South America. The new tomographic image showed the Nazca slab geometry as a continuous fast anomaly, which is consistent with seismic activity and prior slab models. Furthermore, two notable structures were observed: a broad extension of the fast anomaly beneath the Nazca slab at 26–35°S (F1 in Figure 1) and a slow anomaly east of the CTJ (S1 in Figure 1). The checkerboard resolution and recovery tests confirmed the reliability of these large-scale features. The fast anomaly, isolated from the Nazca slab, was interpreted as a relic Nazca slab segment based on its strong amplitude and spatial coincidence with the current Pampean and past Payenia flat slab segments. The slow anomaly near the CTJ was consistent with the previously inferred extent of the Patagonian slab window. Moreover, the active adakitic volcanoes are aligned with the southern edge of the anomaly, and the plateau basalts are located within the anomaly. Our model showed that the slow anomaly extended to a depth of up to 250 km, suggesting a depth limit that the asthenospheric window can influence.

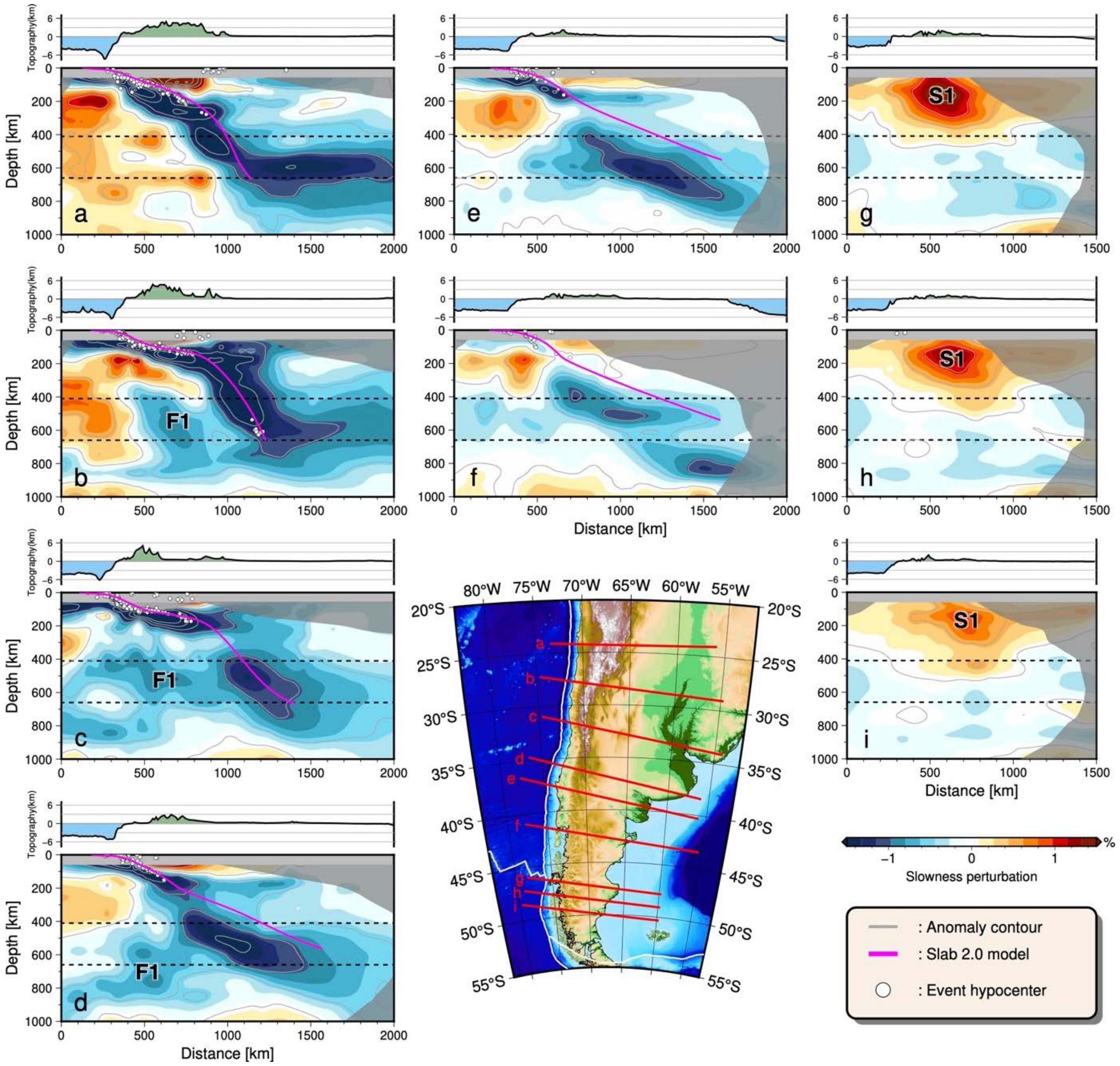

Figure 1. Cross sections of the resulting model approximately perpendicular to the trench strike along profiles (a–i) which are delineated in the map. Two black dashed lines represent the 410 and 660 km seismic discontinuities, respectively. White dots denote the hypocenters of the seismic events. The top surface of the subducting Nazca slab of the Slab2 model (Hayes et al., 2018) is denoted by magenta lines. The topography along the profile is shown above each cross section.

Spatio-temporal evolution of earthquake potential constrained by a physical and statistical approach

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[,*]Equal contribution

Anticipating where and when the next great earthquake can occur is essential to mitigate seismic hazard. However, existing seismic hazard models providing earthquake probability neglect its temporal and spatial evolution and often fail to incorporate adequately uncertainties. Here we combine a physics-based model approach with statistical analysis to assess the spatio-temporal earthquake potential. We take as a working case study the Chilean subduction zone. By integrating Linear Elastic Fracture Mechanics (LEFM) and geophysical constraints, such as seismic coupling and seismogenic width, we evaluate the time Tc at which the fault has stored sufficient elastic energy to allow propagation of large ruptures. Sensitivity tests identify B, a parameter that controls the scaling between fracture energy and final slip, as the most dominant factor modulating Tc. By integrating Tc and moment budget, we show how the likelihood of earthquakes with magnitude exceeding Mw 8.5 evolves in space and time. Our results reveal that interaction between different fault segments can significantly affect earthquake potential. Notably, the 2015 8.3 Mw Illapel event reduced the earthquake potential of neighboring segments. Further, we show that by 2100, the likelihood of earthquakes larger than 8.5 will be 75$\%$ along the Chilean boundary, providing insights on earthquake potential in recognized seismic gaps with pending earthquakes since at least a century. Our work illustrates how physical constraints can contribute to evaluate the space-time evolution of earthquake potential, offering valuable insights that could improve seismic hazard assessment.

True B-Value Estimator Based on Recurrent Neural Network

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Tokyo University of Science

Magnitude frequency distributions usually follow an exponential distribution known as the Gutenberg-Richter (G–R) law, and the exponent is referred to as the b-value. The b-value is estimated for earthquakes sampled from a population following the G–R law with a true b-value, and, therefore, the estimated b-values are not necessarily equal to the true b-values.
In understanding earthquakes as physical phenomena, the true b-value has greater importance. Therefore, determining the b-value that closely matches the true b-value is crucial. In this study, we synthesize earthquake catalogs with a prescribed b-value and develop a true b-value estimator using neural networks.
To create synthetic earthquake catalogs, we use the epidemic-type aftershock sequence (ETAS) simulation, which strictly obeys the ETAS model. The b-value is assumed to vary linearly over time.
To handle the temporal change in the b-value, we configure and apply a recurrent neural network (RNN) to the earthquake catalog. RNNs are well-suited for handling sequential data and can capture temporal dependencies within the data. RNNs also have an advantage in handling different catalogs with various numbers of events, providing a flexible framework for analysis.
After considering multiple types of RNNs, we confirmed that the long-short-term memory (LSTM) network, a variant of RNN, is key to achieving better estimation. LSTM networks enable the model to learn both long-term and short-term dependencies effectively, facilitating stable yet time-variant estimation. Specifically, a bidirectional LSTM allows the model to backtrack and estimate the b-values at previous times retroactively.

Photogeodesy : GNSS, Acoustic and Photogrammetric fusion for underwater centimetric positioning

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GNSS/Acoustic technology enables the measurement of absolute horizontal seafloor displacements through repeated surveys of acoustic beacons over several years. However, a key limitation of this approach is that the beacons must remain underwater for extended periods. In this study, we explore an alternative method that combines photogrammetry and GNSS/Acoustic techniques to determine the absolute positions of distinct seafloor features, such as rocks, outcrops, or shipwrecks. Our approach utilizes an Autonomous Underwater Vehicle (AUV) equipped with a high-resolution digital camera capable of capturing overlapping, near-vertical images with sub-centimetre pixel resolution. The AUV's trajectory is managed using multiple Uncrewed Surface Vessels (USVs), which are geolocated with GNSS systems. This method produces orthorectified images of the seafloor that may still exhibit internal deformations and limited georeferencing accuracy. To address this, we incorporate a temporary GNSS/Acoustic system deployed during the photogrammetric survey. Acoustic beacons are used as ground control points to correct internal distortions within the photogrammetric model and to accurately anchor it to an external reference frame with centimetre-level precision. In this poster, we present the current status of our project and highlight several key challenges that need to be addressed to operationalize this innovative approach.

JUMPy: Automatic Characterization of GNSS Time Series Offsets (Jumps) Using Machine Learning and Bayesian Evidence

Francisco Ortega-Culaciati [1,2], Joaquín Hormazábal [1], Julio Utreras Vargas [3], Fabián Rojas [4], Javier Ruiz [1], Marcos Moreno [5], and Axel Osses [6,2]

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Long-term records of GNSS networks register daily positional time series that include spatio-temporal crustal deformation patterns associated with the seismic cycle. Such observations are crucial to enhance our understanding of the causative geophysical processes, such as those associated with large earthquake generation. For that purpose, GNSS observations are often decomposed into different signals, by fitting a trajectory model built as the superposition of functions that represent the corresponding signals. In that procedure, offsets present in the time series – caused either by geophysical processes (e.g., earthquakes) or human intervention – need to be characterized in order to be able to isolate seismic cycle (inter-, co-, post- seismic) deformation signals as well as Common Mode Error, for instance. Identifying these offsets by visual inspection of the data is challenging, time-consuming and prone to user induced bias. Thus, it is essential to detect and model these offsets in an automatic, robust and consistent manner.

In this work we present a novel two-stage algorithm to characterize offsets in GNSS time series. At the first stage, we take advantage of sparsity inducing regularization methods to identify the time of potential jumps by searching for a parsimonious amount of changes of the coecients of a polynomial model that ts the time series. Subsequently, an ad-hoc representative trajectory model of the time series is built and estimated using the identified times as prior information. The best set of offsets is chosen using the Evidence model class selection method. We test this methodology using realistic simulations of noisy GNSS time series, statistically assessing the goodness and limitations of the proposed methodology. We exemplify its application to observed GNSS time series.

Resolving Near-Trench Interseismic Deformation: Evaluating GNSS-Acoustic Capabilities along the Aleutian Arc

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Understanding the complex coupling behaviors in subduction zones remains a crucial challenge in geodesy. Land-based geodetic stations often fail to capture offshore deformation beyond approximately 40 km, making them unable to resolve subduction coupling in the regions of largest slip and tsunami potential in large earthquakes. Because of this limitation, the physical process of coupling, especially in the shallower near-trench regions of the subduction zone, is still poorly understood. This includes seismic behavior from both giant earthquakes (Mw > 8.5), and a class of events called tsunami earthquakes, which produce tsunamis around 10-30 times larger than expected from its seismic magnitude. Alaska has experienced both such events over the past century, and its rapid convergence allows for high-quality geodetic case studies that can be applied to subduction zones across the globe. Because of this, the region was recently selected for two NSF-funded near-trench studies of geodetic behavior: The Near-Trench Community Geodetic Experiment, and The Mesh GNSS-Acoustic Array design experiment allowing for a dense field of study within just a few km of the trench around the rupture area of a tsunami earthquake that occurred in 1946. All sites were deployed and first measured in the Summer of 2024. Subsequent observations will be made annually over the next few years. Another project was previously funded in 2017.

Here, we evaluate the effectiveness of the distribution of these seafloor geodetic sites for answering questions of large-to-small scale coupling of the megathrust by evaluating the resolvability of individual model patches, using a detailed 3D slab interface (Slab 2.0) modified to account for bathymetry. The modeling efforts here will help to guide future studies (perhaps to densify the coverage) and to improve our understanding of subduction zone earthquakes and tsunamis.

Physical Mechanisms Behind an Unusually Long-Duration Slow Slip Event in the Nankai Trough

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Demian Michael Saffer, Hiroyuki Matsumoto, Shuichiro Yada, Eiichiro Araki,
Narumi Takahashi, Takane Hori, Shuichi Kodaira

JAMSTEC has been monitoring changes in underground fluid pressure, or "pore pressure," using boreholes located near the rupture area of the 1944 Tonankai earthquake in southwestern Japan. These pressure changes are associated with Slow Slip Events (SSEs) occurring along the boundary between the subducting Philippine Sea plate and the overriding Eurasian plate beneath the Nankai Trough. By connecting their borehole observatory (LTBMS) to the seafloor monitoring network (DONET), JAMSTEC now collects real-time pore pressure data, enabling continuous updates to the SSE catalog.

An updated catalog revealed an anomaly: the SSE that occurred in February 2012 lasted significantly longer than other similar events. Researchers analyzed pore pressure and seafloor pressure data to uncover the underlying reasons. The results showed that the February SSE progressed more slowly and lasted longer due to two main factors: internal and external influences.

Internally, the SSE occurred in a region with low stress accumulation on the fault, resulting in slower slip behavior consistent with frictional properties of faults. Externally, changes in seafloor pressure—driven by variations in the Kuroshio Current, a major ocean current—coincided with the conclusion of the February SSE. This suggests that the meandering of the Kuroshio Current may influence the duration of SSEs.

This study highlights that SSEs are not only governed by fault mechanics but also modulated by environmental factors such as ocean currents and atmospheric pressure. Understanding these influences is crucial for improving the prediction of such events. These findings are detailed in a paper accepted by *Tectonophysics* (https://doi.org/10.1016/j.tecto.2024.230439).