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# Chilean Scientific Community Workshop

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Termas El Corazón, Chile



## ORGANIZING COMMITTEE

Alvaro Amigo Ramos (Servicio Nacional de Geología y Minería)  
Sergio Barrientos (Centro Sismológico Nacional, Universidad de Chile)  
Andrés Tassara (Universidad de Concepción)  
Laura Bono Troncoso (Servicio Nacional de Geología y Minería)  
Emily Brodsky (University of California Santa Cruz, SZ4D)  
Mike Brudzinski (Miami University, SZ4D)  
George Hilley (Stanford University, SZ4D)  
Diana Roman (Carnegie Institution for Science, SZ4D)  
Harold Tobin (University of Washington, SZ4D)

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[CONTACT@SZ4D.ORG](mailto:CONTACT@SZ4D.ORG)

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## REMARKS FROM THE ORGANIZING COMMITTEE

Estimados y estimadas colegas,

A nombre del Comité Organizador Local, nos sentimos honrados de contar con su valiosa participación en este evento, que reunirá por primera vez a más de 60 investigadores y estudiantes de postgrado provenientes del ámbito académico, público y privado, junto al Comité Ejecutivo de la iniciativa científica SZ4D. Al mismo tiempo, se ha logrado una importante representación regional, lo que sin duda ofrecerá perspectivas complementarias sobre el estado de las investigaciones de las Ciencias de la Tierra en Chile y, en qué grado estos procesos afectan la vida de las personas y la infraestructura crítica del país.

El principal objetivo del encuentro corresponde a sentar las bases para establecer colaboración científica entre SZ4D y la comunidad científica local, orientada a lograr una mejor comprensión de los fenómenos derivados del proceso de subducción. A su vez, se buscará discutir sobre desafíos en cuanto a instrumentación y su complementariedad con las redes existentes en temáticas relacionadas con *Landscapes and Seascapes* (LS), *Faulting and Earthquakes Cycles* (FEC) y *Magmatic Drivers of Eruptions* (MDE). Lo anterior busca que el conocimiento generado sea de alto impacto científico, pero a su vez de utilidad en la gestión del riesgo ante desastres derivados de los procesos geológicos. En suma, se espera que una detallada comprensión del sistema Andino resulte en un modelo a seguir para zonas con características similares en el mundo.

Adjunto a este correo se encuentra la agenda tentativa a desarrollarse durante los días del evento, la que incluye además una reunión dedicada a los investigadores jóvenes al inicio de la jornada, aunque abierta a todos y todas quienes deseen participar.

Finalmente, agradecemos al SZ4D por el interés de escuchar a la comunidad nacional y materializar este significativo acontecimiento, además del patrocinio de la Sociedad Geológica de Chile y *US National Science Foundation*, lo que nos permitió llegar de manera expedita a todos Ustedes.

¡Esperamos encontrarnos pronto en las Termas El Corazón!

## REMARKS FROM THE ORGANIZING COMMITTEE

Dear colleagues,

On behalf of the Local Organizing Committee, we are honored to have your valuable participation in this event, which will bring together for the first time more than 70 researchers and postgraduate students from academic, public and private institutions, together with the Executive Committee of the SZ4D scientific initiative. At the same time, an important regional representation has been achieved, which will undoubtedly offer complementary perspectives on the state of the Earth Sciences research in Chile and to what extent these processes affect the lives of people and the critical infrastructure of the country.

The main objective of the meeting is to lay the groundwork for scientific collaboration between SZ4D and the local scientific community, aimed at achieving a better understanding of the phenomena derived from the subduction process. Furthermore, we will discuss challenges focused on instrumentation, complementary to the existing networks on the topics related to Landscapes and Seascapes (LS), Faulting and Earthquakes Cycles (FEC) and Magmatic Drivers of Eruptions (MDE). The above seeks that the knowledge generated to be of high scientific impact, but at the same time useful in disaster risk management derived from geological processes. In summary, it is expected that a detailed understanding of the Andean system will result in a model to follow in similar areas worldwide.

Attached to this email is the tentative agenda to be developed during the days of the event, which also includes a meeting dedicated to young researchers at the beginning of the seminar, but open to all those who wish to participate.

Finally, we thank SZ4D for their interest in listening to the national community and materializing this significant event, as well as the sponsorship of the Geological Society of Chile and the *US National Science Foundation*, which allowed us to reach all of you in an expeditious manner.

We look forward to welcoming you at Termas El Corazón!

## V<sub>P</sub>/V<sub>S</sub> STRUCTURE AND GEODYNAMICS OF THE NAZCA RIDGE

Eduardo Contreras-Reyes, Sebastian Obando-Orrego, Valeria Cortés-Rivas, Anne Krabbenhoeft, and Andrei Maksymowicz

The Nazca Ridge (NR) was formed near the interaction of a hotspot mantle plume and an active spreading center. We use active-source seismic data to obtain 2-D V<sub>P</sub> and V<sub>S</sub> tomographic models. Results show a ~2 km thick seismic layer 2A with V<sub>P</sub>/V<sub>S</sub> values of 1.75-1.85 in the uppermost crust interpreted as pillow basalts with a low degree of fracturing and/or hydrothermal alteration. The 2A/B boundary layer presents V<sub>P</sub>/V<sub>S</sub> values of 1.76-1.79 consistent with pillow basalts/sheeted dykes units. The NR crust (~15 km thick) requires an increment of the asthenospheric mantle potential temperature in ~100°C formed by passive adiabatic decompression melting.

## THE TRIGGERING OF PLINIAN AND SUB PLINIAN ERUPTION IN THE SOUTHERN VOLCANIC ZONE: AN IN SAR PERSPECTIVE

Francisco Delgado

The Southern Volcanic Zone is the most productive magmatic arc during 1989-2019 and is thus a key location to address how are large explosive eruptions triggered in subduction zones. In this presentation I will focus on InSAR observations of ground deformation recorded before the VEI 5 2008-2009 Chaitén, VEI 4-5 2011-2012 Cordón Caulle and VEI 4 2015 Calbuco eruptions where the triggering mechanism is far more complex than a simple mechanism of pre-eruptive magma injection.

## THE REACTIVATION OF CRUSTAL PLATE FAULT CONSEQUENCES OF THE VISCOELASTIC RELAXATION THE PISAGUA RUPTURE, NORTHERN CHILE

Mahesh N Shrivastava, Gabriel Gonzalez, Pablo Salazar, Marcos Moreno, and Juan Carlos Baez

On September 11th, 2020, a Mw 6.3 earthquake and aftershocks took place in the coastal region of northern Chile, revealing the reactivation of the deep segment of upper plate fault in the south of the Pisagua earthquake 2014 rupture zone. The post-seismic relaxation process may provide a key role for understanding the future earthquake in the short and long term in the contiguous region. During the early post-seismic phase, the rupture zone relaxes elastically (in afterslip from months to year) and viscoelastic (year to decade). At the same time the adjacent region gets stressed and releases with the moderate earthquake. In the presence of deep-rooted crustal fault in the adjacent may activate. Therefore, it is equally important to identify the seismically locked zone as well as the crustal fault scenario for seismic hazards assessment.

## CHANGING LANDSCAPES: SEDIMENT SOURCES AND PATHWAYS IN THE ANDES (PATAGONIA AND CENTRAL CHILE)

Tania Villaseñor Jorquera, Ismael Contreras, Marco Pfeiffer, Alida Perez, Kathleen Marsaglia, Daniel Tentori, and Luisa Pinto

This poster summarizes recent and current investigations on the study of sediment sources and pathways in relation to landscape dynamics of erosion at different scales of space and time. A sediment core offshore northern Patagonia was studied to infer hotspots of erosion in the Patagonian Andes during the Middle-Late Pleistocene. In addition, preliminary results of the study of the sources of suspended sediment in a fluvial basin in central Chile, its variability at the seasonal scale, and its relation to modern landscape dynamics in the Andes of central Chile will be discussed.

## RECENT UPLIFT AND DEFORMATION IN THE WESTERN COASTAL CORDILLERA IN CENTRAL CHILE

María Pía Rodríguez, Benjamín Guerrero, Alfonso Encinas, Germán Aguilar, and Luisa Pinto

The sedimentary facies and U-Pb zircon dating of La Cueva Fm in the western Coastal Cordillera (WCC) of central Chile indicate that the coastline was located 30 km to the east of the present-day coast at ~ 6 Ma and that marine sedimentation was sealed by a lahar at ~ 4 Ma. The lahar was uplifted and tilted ~ 6° to the east at ~ 2-1 Ma according to <sup>10</sup>Be exposure ages. The distribution of Chi values is consistent with an inversion of drainage towards the east. The geometry of the WCC block resembles the retrowedge of a subduction wedge.

## CARIÑO BOTADO FAULT: AN EVIDENCE OF ACTIVE TECTONICS ON THE WESTERN BORDER OF THE CHILEAN PRINCIPAL CORDILLERA (32.8°S)

Luisa Pinto, J. Estay, G. Easton, and G. de Pascale

Along the western slope of the Chilean Principal Cordillera (~32.8°S), there is quaternary tectonic activity within a mayor and old structural system (Pocuro Mega-Fault) spread over a large faulted and altered zone (~0.5-2 km wide). The principal reverse fault (~40°E), Cariño Botado Fault, has an exposed surface trace (>5 km long) and produced a long-live uplift (~5-30 m), evidenced on morphostructural markers. The full understanding of this quaternary fault has strong implications regarding its correlations to other southern faults and on seismic hazard for the cities close to these faults.

## DIFFSIMUL: A FRIENDLY-USER GRAPHICAL USER INTERFACE TO DETERMINE MAGMATIC TIMESCALES

Eduardo Morgado, and Dan J. Morgan

The timescales of magmatic processes are crucial for volcano monitoring and magmatic systems understanding. Diffusion chronometry is a technique which allows us to calculate those timescales. Here, we present DiffSimul, a MATLAB-based friendly-user graphical user interface (GUI) to determine magmatic timescales. It works for internally- and externally-buffered compositional profiles in several solid magmatic phases: olivine, melt (melt inclusions), Fe-Ti oxides, clinopyroxene, and orthopyroxene. DiffSimul freeware solves Fick's second law equation for Cartesian and Spherical coordinates via the finite element method.

## SEISMIC EVENT DETECTION AND LOCATION AUTOMATION PLATFORM: PRELIMINARY RESULTS AND IMPLEMENTATION IN OVDAS

Ivo Fustos-Toribio, Millaray Curilem, Fernando Huenupan, Cesar San Martin, Jaime Diaz, Daniel Vasquez, Diego Vega, and Maria Jose Castilla

An automatic localization system was implemented at the Nevados del Chillan Volcanic Complex. The detection and classification used a continuous wavelet transform and machine learning approach, respectively. Moreover, P and S onsets are estimated for all the seismic stations of OVDAS using a multiparametric approach. We located seismic events using the hyposat model in real-time. The location results provide an RMSE better than 0.8 s in 80% of the cases. These results were coupled to a web interface, allowing to OVDAS personnel evaluate the temporal changes in the seismic activity of the complex in the short and medium-term.

## THE CSN STRONG MOTION DATABASE

Felipe Leyton and Bruno García

The National Seismological Center of the University of Chile has a bit over 100 complete seismological stations installed throughout the national territory, sending their data in real time. In addition, the CSN manages the National Accelerometer Network, which has almost 400 acceleration sensors installed in locations throughout the country. With all these data, the Strong Movement Database has been generated, considering all the significant records registered by both networks. In this work, this database is presented, as well as the user interfaces. In addition to this, several properties are shown, characterizing the sites of these stations, such as: geological description, estimation of the spectral ratio of the horizontal component over the vertical noise and response spectra, estimates of the shear wave velocity, etc.

## TEMPORAL EVOLUTION OF A SUBDUCTING ACTIVE SPREADING RIDGE: A 2D NUMERICAL APPROACH OF THE CHILE TRIPLE JUNCTION

Jorge Sanhueza, Gonzalo Yáñez, Roger Buck, and Jaime Araya Vargas

The temporal evolution of subduction zones involves different settings: subduction initiation/cessation and self-sustaining subduction. However, the subduction of an active spreading ridge implies a particular scenario given by the interaction of a buoyant magma chamber and the opening of a slab window beneath the continent. We used 2D petrological-thermomechanical models in order to replicate the subduction of the Chile Ridge beneath South America incorporating partial melt in the asthenosphere. Preliminary results are consistent with the detachment of the Nazca plate and also suggest that the slab pull and the partial melt evolution play a key role in the long-term geodynamics.

## CHARACTERIZING b-VALUE VARIATIONS WITH A BAYESIAN TRANS-DIMENSIONAL APPROACH: APPLICATION TO CENTRAL CHILE SEISMIC GAP

Catalina Morales-Yáñez, Luis Bustamante, Roberto Benavente, Christian Sippl, and Marcos Moreno

The b-value characterizes the seismic activity for a given earthquake catalog. Here we develop an algorithm to estimate variations of b-value along one arbitrary dimension objectively. We use a Bayesian transdimensional approach called reversible jump Markov chain Monte Carlo (rjMCMC). With this methodology, the seismic domains will be self-defined according to information in the seismic catalog, making it unnecessary to prescribe domains. We first show the algorithm's robustness by performing regressions from synthetic catalogs. We also apply the algorithm to a microseismicity catalog for the Central Chile region. Our results indicate the reliability of the method in capturing arbitrary b-value variations.

## PRIMITIVE MONOGENETIC VOLCANOES: ULTRAFAST DELIVERY OF A HOT SOUP

Pablo Salas, Philip Ruprecht, Laura Hernández, and Osvaldo Rabbia

The notion of arc volcanism includes the prevalence of several levels of magma accumulation in the crust, where magma mixing occurs repeatedly in the long term with continuous crystallization. These intracrustal levels places a major difficult for mantle-equilibrated primitive magmas to reach high crustal levels due interception of such reservoirs imply cooling, triggering crystallization and increasing the viscosity. However, some magmas do the transcrustal passage in very restricted timescales, reaching the surface and preserving key information about the earliest stages of crystal growth, zoning and melt composition. This poster shows Los Hornitos volcanoes as an example of this of volcanoes.

## TIME-SERIES DATA TO DETERMINE HEAT AND SOLUTE BUDGETS IN THE SOUTHERN ANDES

Alida Perez-Fodich, Pablo Sanchez-Alfaro, and Carolina Muñoz-Saez

The Southern Volcanic Zone of the Andes hosts more than 25% of surface hydrothermal manifestations in Chile. Several of the Holocene volcanoes of the SVZ show hydrothermal activity, indicating elevated geothermal gradients in the volcano surroundings. High rainfall rates in the SVZ result in multiple volcanic catchments feeding the larger rivers flowing towards the Pacific. We hypothesize that hydrothermal activity in the SVZ can affect both temperature and solute concentrations in these streams. We present new time-series temperature and conductivity data coupled with geochemical tracers to determine solute fluxes and heat budgets released through hydrothermal activity in volcanic catchments.

## IDENTIFICACIÓN DE FACIES SISMOGÉNICAS Y TSUNAMIGÉNICAS, ASOCIADAS A PALEO TSUNAMI MIOPLIOCENO DE LA FM HORCÓN

Ximena Contardo y Cristian Rodrigo

Identificar y comprender la naturaleza de los depósitos de tsunamis en el pasado geológico y los mecanismos que lo generaron, resulta altamente relevante para los márgenes en subducción, particularmente en zonas litorales, que experimentan una creciente expansión inmobiliaria, incrementando la vulnerabilidad de la población. Los actuales sistemas de alerta permiten prevenir a la comunidad ante la ocurrencia de terremotos tsunamigénicos, ya sea de fuente cercana o lejana, particularmente relacionados a mecanismos conocidos de subducción, poco se evalúa respecto de otros procesos, que pueden determinar una recurrencia e intensidad distinta, tales como subducción de seamounts, colapso de islas oceánicas u otros.

## GEOMORPHOLOGICAL AND GEODETIC INTERSEISMIC DEFORMATION RATES IN THE SALAR GRANDE FAULT, NORTHERN CHILE

Tamara Aranguiz, Alison Duvall, and Brendan Crowell

In Northern Chile, the Salar Grande Fault (SGF) is a strike-slip fault system characterized by: strong geomorphic expression, hyper-arid conditions, and unknown slip rates. To assess its seismic hazard and to test recent landscape model predictions in an end member environment, we calculate the interseismic horizontal motion of the SGF. Based on morphofluvial analysis and residual GNSS analysis, we estimated a range of slip rate between  $\sim 1$  mm/yr and 3.65 mm/yr. The comparison of the two time-scale slip rates contribute to the understanding of the fore-arc faults evolution in a highly coupled subduction zone region.

## GEOMORPHOLOGY OF THE SIMPSON SUBMARINE CANYON, 44°S, CHILE

Cristian Rodrigo, Matías Fernández, Nitza Garrido, Ximena Contardo, and Rodrigo Fernández

The Simpson Submarine Canyon is located between Chiloé Island and the Taitao Peninsula. Multibeam bathymetric data were processed to obtain a DTM. Slope escarpments and topographic irregularities could be associated with the regional tectonics. On the canyon walls, erosion and transport processes dominate, evidenced by gullies, channels, and mass removals, which leave debris on the axis. We report: a large landslide from a canyon wall, which could be due to a high-energy event such as an earthquake; and the generation of a large sediment wave field outside the canyon mouth, indicating a great activity by sedimentary processes.

## STRESS FIELDS AND DEFORMATION ASSOCIATED WITH MAGMA SHEET INTRUSION INTO HETEROGENEOUS INCLINED LAYERED SEQUENCES

John Browning, Matias Clunes, Carlos Marquardt, Jose Cembrano, and Agust Gudmundsson

For magma chambers to form or volcanic eruptions to occur magma must propagate through the crust as sheets. Most models that investigate magma paths assume the crust to be either homogeneous or horizontally layered and composed of rocks of contrasting mechanical properties. In subduction regions that have experienced orogenesis, like the Andes, the crust has been deformed, resulting in rock layers that are commonly folded and dipping. The assumption of homogeneity or horizontal layering then does not capture all of the potential magma path-crustal interactions. We tackle this problem by determining the effect of a crust made of steeply inclined layers in which sheets are emplaced.

## GENERATION OF ARC DACITE BY MAGMA MIXING/MINGLING PROCESSES AND ITS RELATIONSHIP WITH MAGMATIC FOCUSING AND THE CONFIGURATION OF THE PLUMBING SYSTEM: AN EXAMPLE FROM THE LAST NEVADOS DE CHILLÁN VOLCANIC COMPLEX ERUPTIONS, SOUTHERN ANDES, CHILE

Andrés Oyarzún, Luis Lara, and Andrés Tassara

Studying the petrogenesis of intermediate compositions is relevant for understanding the evolution of the continental crust and for the volcanic risk. Magma mixing is one of the most common processes to generate intermediate compositions and to trigger eruptions. Our results support an origin of recent dacites of the Nevados de Chillán by magma mixing processes. Unlike the older rocks, these compositions predominate in the younger eruptive products of the Nevados de Chillán. We propose that the storage of evolved magmas in the upper crust and the magmatic focusing over time, increases the chances of generating dacites by magma mixing processes.

## SEISMIC REFLECTION IMAGING OF THE ANDREANOF SEGMENT OF THE ALEUTIAN SUBDUCTION ZONE AND A COMPARISON WITH THE CHILEAN MARGIN

Valeria Cortés Rivas, Donna Shillington, Dan Lizarralde, Justin Estep, Hannah Mark, and Brian Boston

We present new constraints on the structure of incoming plate and forearc of the Andreanof section of Aleutian Islands from two MCS profiles. These lines image regions with different megathrust behavior: the Adak section has a history of large earthquakes and tsunamis and high coupling, whereas the Atka section shows little coupling and fewer large earthquakes. The incoming plate presents similar characteristics in both regions, but the forearc exhibits different patterns of cumulative deformation. We compare our results with seismic imaging in the Chilean margin to discuss how the seismic behavior and locking relate to the deformation of the forearc.

## FULLY JOINT INVERSION OF THE 2016 Mw 7.6 CHILOÉ EARTHQUAKE AND ITS RELATION TO THE INTERSEISMIC RECUPERATION OF THE GIANT 1960 VALDIVIA MEGATHRUST INTERPLATE ZONE

Sophie Peyrat, F. Bravo, F. Delgado, M. Fuentes, B. Derode, A. Perez, and J. Campos

A large (Mw 7.6) megathrust earthquake occurred on 25 December 2016 in Southern Chile, south of the Chiloé Island (74.2°W, 43.3°S) in the South America - Nazca subduction zone. This earthquake was the first large event in this seismotectonic segment since the Mw 9.5 1960 Valdivia megathrust earthquake, and broke a ~50 km long segment of the southern part of its rupture zone. Source parameters are inferred from teleseismic broadbands, strong motions, GPS, cGPS, InSAR, and tide gauge data. We show that the joint inversion significantly improves the resolution of the slip distribution, taking advantage of each dataset. Our slip models predict a single slip patch of 70 km x 60 km with a maximum slip of  $3.2 \pm 0.8$  m and a moment magnitude of 7.64. Previous suggestions that the Chiloé earthquake released energy accumulated before the Valdivia earthquake are not supported by the ensemble of geodetic, seismological and tsunami data. Hence the Chiloé earthquake most likely released all the strain accumulated in the rupture area since the 1960 earthquake.

## DEPTH VARIATION IN MEGATHRUST RUPTURE EXPLAINS THE TSUNAMI GAP IN METROPOLITAN CHILE

Matías Carvajal, Marco Cisternas, Kelin Wang, Marcos Moreno, and Daniel Melnick

Newly found first-hand accounts of coastal uplift and tsunamis provide unambiguous historical evidence for successive rupture variations in the dip direction in the central Chile megathrust.

## STOCHASTIC FAULT PATTERNS: AN APPROXIMATION TO THE RUPTURE COMPLEXITY OF TSUNAMIGENIC EARTHQUAKES

Juan González, Rafael Aránguiz, Gabriel González, Roberto Benavente, Joaquín Cortés-Aranda, Mahesh N. Shrivastava, and Natalia Zamora

Tsunamigenic earthquakes ( $M_w > 8$ ) occurring in the South American subduction zone are a relevant threat to coastal communities. Usually, the parameters obtained for the seismic source geometry for tsunamigenic earthquakes and the published scaling relationships are used as input for tsunami hazard estimation using uniform slip models. The implementation of stochastic rupture scenarios provides reasonable fits to historical reports of inundation measurements, but it is possible to observe high variability in the results obtained. The maximum rupture slip may be a relevant causal control for estimating inundation measurements under non-breaking wave conditions, the variability may be affected by other factors such as bay resonance and other local effects controlled by coastal geomorphology.

## GEOLOGIC EVIDENCE OF THE LARGEST HISTORICAL TSUNAMI OF METROPOLITAN CHILE CONSTRAINS TSUNAMI HAZARD IN THE COUNTRY'S MOST POPULATED COAST

Marco Cisternas and Matías Carvajal

The coast of Metropolitan Chile, sandwiched between the rupture areas of the southern 2010 and northern 2015 tsunamigenic earthquakes, lacks destructive tsunamis in 290 years, since 1730. It has been suggested the 1730 tsunami ensued a large megathrust earthquake with shallow slip. Here, we report robust geologic evidence of this tsunami and use it to test—by tsunami modelling—this hypothesis. Evidence comes from a former coastal lagoon 30 km north of Valparaíso. Our results are indeed best explained by a large shallow rupture. If true, the next earthquake could pose a complex scenario for the country's most populated coast.

## SLIP BEHAVIOR OF VELOCITY-WEAKENING BARRIERS

Diego Molina, Jean-Paul Ampuero, and Andrés Tassara

Seismic barriers are fault portions that promote earthquake rupture arrest and fault segmentation. Despite their fundamental role in controlling the maximum magnitude of earthquakes, the nature of seismic barriers is still uncertain. A common interpretation of barriers as having velocity-strengthening (VS) friction, i.e. steady-state friction increases with increasing slip velocity, is inconsistent with the thermal control of friction observed in laboratory experiments which implies that most subducted VS materials eventually turn velocity-weakening (VW) at some depth. Here we examine the possibility of VW barriers by conducting earthquake cycle simulations along a VW megathrust segmented by lateral variations of frictional properties and normal stress. We show that VW fault segments display a wide range of behaviors, including permanent barrier behavior. We quantify the efficiency of VW barriers in arresting ruptures by a non-dimensional parameter based on fracture mechanics theory which can be constrained by observations on natural faults.

# SEISMIC CYCLE SLIP SEGMENTATION CONSIDERING GEOMETRICAL AND NORMAL STRESS ANOMALIES ALONG THE CHILE SUBDUCTION ZONE

Marco Herrera, J.G.F. Crempien, J. Cembrano, M. Moreno, and A. Tassara

Subduction earthquakes show complex spatial and temporal patterns, exhibiting events of different sizes and recurrence, defining different fault segments separated by barriers. Thus, identifying these barriers is critical for seismic and tsunami hazard estimations. We perform two subduction seismic cycle models on Chilean subduction zone (18°-45°S) with a quasi-dynamic approach, both with a non-planar subduction interface geometry but the second model incorporates effective vertical stress anomalies (VSA) constrained with gravity anomalies along the subduction zone. After 5,000 years of effective simulation, both models show Mw8.0-9.3 earthquakes that define different segments. Our results show that subduction geometry controls the first-order patterns of large earthquake rupture sequences, inducing a spatial segmentation of the seismic cycle slip. And VSA are a second-order segmentation of the subduction zone, remarking the barriers.