

The Cascadia Region Earthquake Science Center (CRESCENT): Advancing Understanding of Cascadia's Earthquake Hazards

Diego Melgar^{*}  *et al.*

Abstract

The Cascadia subduction zone (CSZ) is capable of producing large megathrust earthquakes and tsunamis, posing substantial risks to the Pacific Northwest. This article examines the seismic characteristics of the CSZ, including its offshore coupling, sparse seismicity, and a complex paleoseismic record. Recent advances in geophysical methods and data collection have improved our understanding of subduction zone processes, but important uncertainties remain regarding rupture dynamics, ground shaking, and tsunami impacts. The Cascadia Region Earthquake Science Center (CRESCENT) has been established to address these challenges through coordinated research, education, and community engagement. By integrating scientific studies, fostering collaboration, and leveraging new technologies, CRESCENT seeks to improve hazard assessment and resilience in the region. This article outlines the primary challenges and opportunities for advancing subduction-zone science and supporting societal preparedness for future CSZ events.

Cite this article as Melgar, D., A. M. Thomas, V. Sahakian, P.-E. Share, A. Meigs, H. Tobin, L. Staisch, T. Melbourne, J. Elizabeth, R. Ajala, *et al.* (2026). The Cascadia Region Earthquake Science Center (CRESCENT): Advancing Understanding of Cascadia's Earthquake Hazards, *Seismol. Res. Lett.* **XX**, 1–18, doi: [10.1785/0220250318](https://doi.org/10.1785/0220250318).

Introduction: The Cascadia Subduction Zone

The largest and most damaging earthquakes happen at subduction zones. Their associated hazards such as strong shaking, tsunamis, landslides, liquefaction, and fire make them some of the most dangerous natural phenomena (Daniell *et al.*, 2011). As a result, subduction zones have been the subject of intense scientific scrutiny (e.g., Wirth *et al.*, 2022) that has resulted in substantial growth with respect to our understanding of their physics and consequences to humans and the built environment. However, much work remains to comprehensively understand subduction zone geohazards, particularly in areas such as controls on along-strike and down-dip rupture propagation, long-term earthquake cycles, slow earthquakes, and tsunami generation mechanisms, which are critical for improving hazard estimates and developing mitigation strategies.

The Cascadia subduction zone (CSZ, Fig. 1) is a seismically active convergent margin that spans the Pacific Northwest United States and southwestern Canada (Clague, 1997). Like other subduction zones, this dynamic and complex plate boundary can produce some of the largest earthquakes and tsunamis on Earth. The 1700 megathrust earthquake, for example, generated a tsunami powerful enough to damage coastal Japan, thousands of kilometers away across the Pacific Ocean (Satake *et al.*, 1996; Yamaguchi *et al.*, 1997). Despite its ability

to produce great earthquakes, the CSZ is unusual among subduction zones owing to its low ambient seismicity levels (Bostock *et al.*, 2019) and lack of earthquakes along the subducting interface (interplate) during historical times. Deep earthquakes inside the subducted plate (intraplate) have been responsible for the vast majority of infrastructure damage and casualties in recent years (e.g., Chang and Falit-Baiamonte, 2002) and provide information about mechanical and petrologic processes in the downgoing slab (e.g., Ichinose *et al.*, 2004). Similarly, crustal events at its complex southern terminus, the Mendocino triple junction, can often involve diverse structures (Yeck *et al.*, 2023; Hellweg *et al.*, 2024) and have widespread effects, including the last substantial local tsunami (González *et al.*, 1995). The CSZ is an end-member warm-slab subduction zone and serves as a type locality for slow earthquakes and related phenomena, which remain enigmatic and the focus of much study (e.g., Ide and Beroza, 2023).

Owing to the breadth and depth of basic science research focused on Cascadia, contemporary and legacy data collection efforts, and technological innovations, the CSZ provides an environment conducive to further progress in subduction zone

Full author list and affiliations appear at the end of this article.

*Corresponding author: dmelgarm@uoregon.edu

© Seismological Society of America

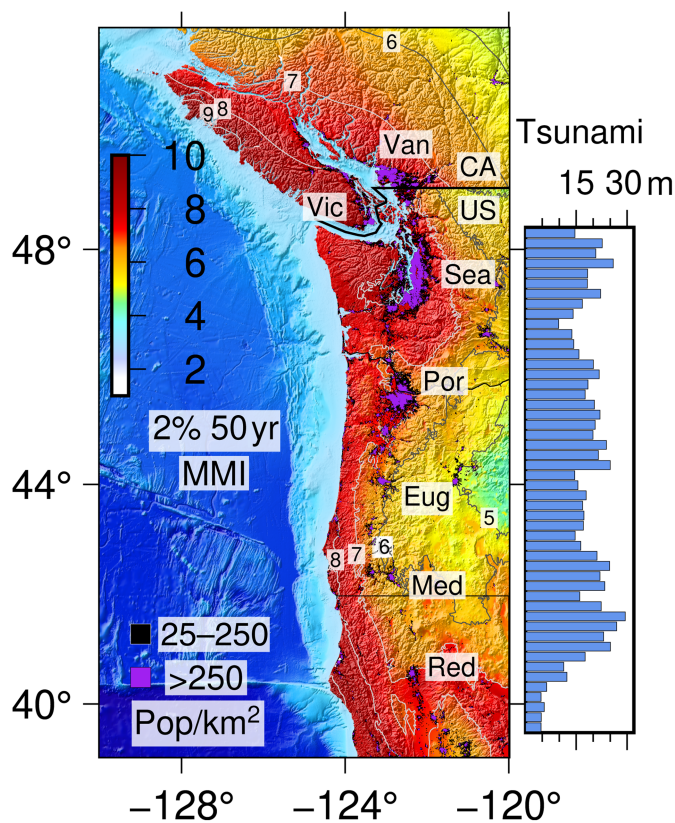


Figure 1. Overview of earthquake hazards along the Cascadia subduction zone (CSZ). Colors and contours are the modified Mercalli intensity (MMI) levels with a 2% probability of exceedance in a return period of 50 yr. Estimates are from the United States (US) and Canada (CAN) official seismic hazard maps (Kolaj *et al.*, 2023; Petersen *et al.*, 2024); note the clear discontinuity at the U.S.-Canada border reflective of different methodologies used. Tsunami amplitudes for the U.S. coastline are shown and come from the XXL1 rupture model used for evacuation planning in the region (Witter *et al.*, 2011). Population density estimates are from LandScan (Weber *et al.*, 2022; Lebakula *et al.*, 2024). Population centers labeled are (Vic)toria, (Van)couver, (Sea)ttle, (Por)tland, (Eug)ene, (Med)ford, and (Red)ding. Background shaded relief and bathymetric maps are sourced from Becker *et al.* (2009). The color version of this figure is available only in the electronic edition.

science. For example, data acquired during on- and offshore data collection efforts (e.g., Toomey *et al.*, 2014; Carbotte *et al.*, 2024) have revealed new insights into the structure of both the downgoing and overriding plates. This structure, and many other geophysical observables, vary considerably along the strike of the Cascadia fore-arc, providing an opportunity to understand the causes and effects of segmentation (e.g., Delph *et al.*, 2021; Carbotte *et al.*, 2024). For some applications, machine learning and artificial intelligence can be deployed to analyze large volumes of data faster and more accurately than humans can (e.g., Kong *et al.*, 2019). This capability enables the creation of high-resolution catalogs of microseismicity that can be used to determine multiscale fault structure, probe fault rheology in space and time, estimate future ground motions,

and so forth. Noise interferometry and distributed acoustic sensing can yield better characterization of shallow velocity structure (e.g., Wang *et al.*, 2019; Spica *et al.*, 2020), which can be used to estimate future strong ground motions. Finally, the neighboring Gorda and Explorer microplates, Queen Charlotte, and Mendocino triple junctions provide opportunities to elucidate the complex stress and deformation patterns resulting from plate boundary interactions and better understand the implications for hazard (Littel *et al.*, 2023; Hellweg *et al.*, 2024).

In both the United States and Canada, the CSZ is recognized as a substantial source of seismic hazard (Fig. 1). Though our western understanding of the threats posed by the CSZ only took hold in the 1980s (e.g., Atwater, 1987), the rich native oral traditions from Tribes across the region have warned of Cascadia's seismicity for centuries and are an important archive of regional and local hazards (Thrush and Ludwin, 2007). It is now widely understood that there is a high risk for loss of life, injury, and damage to physical infrastructure from a variety of different seismic and tsunami sources. The U.S. National Seismic Hazard Model (NSHM), as well as the Canadian seismic hazard model (CASHM), draw from the state-of-the-art knowledge of earthquake science (Kolaj *et al.*, 2023; Petersen *et al.*, 2024). Both predict high likelihood of strong shaking (modified Mercalli intensity > 6–7) in almost all population centers throughout the region (Fig. 1). However, most major infrastructure in the region predates 1980, and the unreinforced masonry, impossibly long tsunami evacuation distances, precarious lifelines, and other fragilities that remain pose unresolved challenges to public safety and lower resilience (RaghuNandan *et al.*, 2015; Wood *et al.*, 2015, 2016). Tsunami impact maps routinely show inundation of entire towns and incapacitation of emergency response buildings and other critical facilities (e.g., Oregon Department of Geology and Mineral Industries, 2013). Losses of up to \$100–\$300 billion U.S. dollars can be expected (e.g., Belenky *et al.*, 2014), with decades of economic and social impacts reverberating nationally due to business interruption and displaced populations (Oregon Seismic Safety Policy Advisory Commission [OSSPAC], 2013).

Scientifically, the CSZ has been home to many key discoveries, and still today presents a diversity and breadth of open questions. In addition, there is a deep need in the region for research as one of many tools toward societal needs, requiring capacity building in the workforce (Sahakian *et al.*, 2026). A nexus for the scientific community in partnership with regional resilience and workforce development entities could accelerate the progress of scientific advances, positioned within a societal framework.

Cascadia Region Earthquake Science Center (CRESCENT)

In 2023, the National Science Foundation funded the Cascadia Region Earthquake Science Center, CRESCENT. CRESCENT

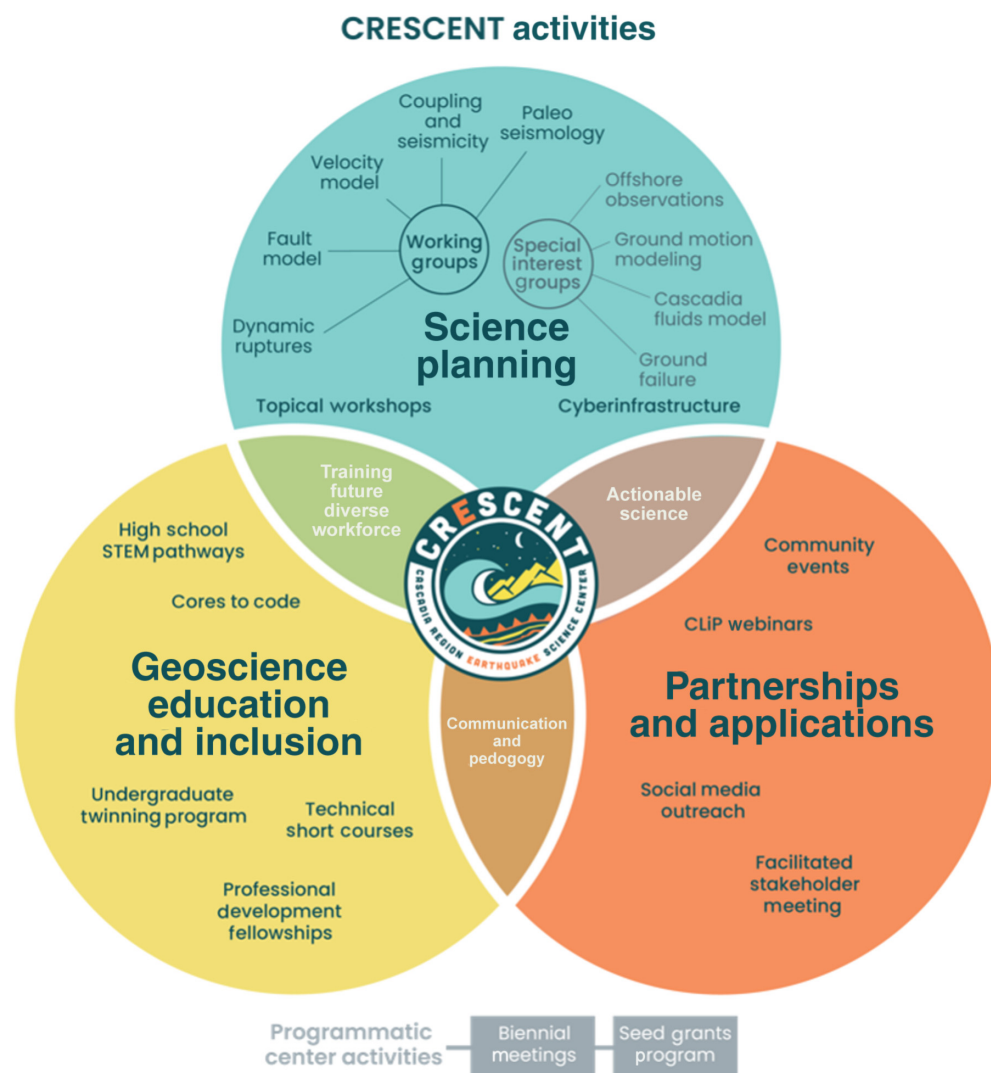


Figure 2. Three pillars that are the foundation of CRESCENT. The color version of this figure is available only in the electronic edition.

is the nation's first subduction zone earthquake hazards center—a nexus for earthquake science and hazards research. CRESCENT's three pillars focus on doing scientific research contextualized by and designed for advancing our basic understanding of processes in tandem with addressing societal needs and building capacity in the necessary workforce (Sahakian *et al.*, 2026; Fig. 2).

CRESCENT's first goal is to advance foundational understanding of CSZ earthquakes and their associated hazards, and to transfer this knowledge to other subduction zones. To accomplish this, CRESCENT's activities are separated among three interconnected pillars (Fig. 2): Science Planning, Geoscience Education and Inclusion (GEI), and Partnerships and Applications (P&A). The GEI and P&A pillars have the goals of expanding access to modern geoscience careers and of connecting the science of CRESCENT to the broad geohazards community of practice; they are described in detail in the companion piece by Sahakian *et al.*

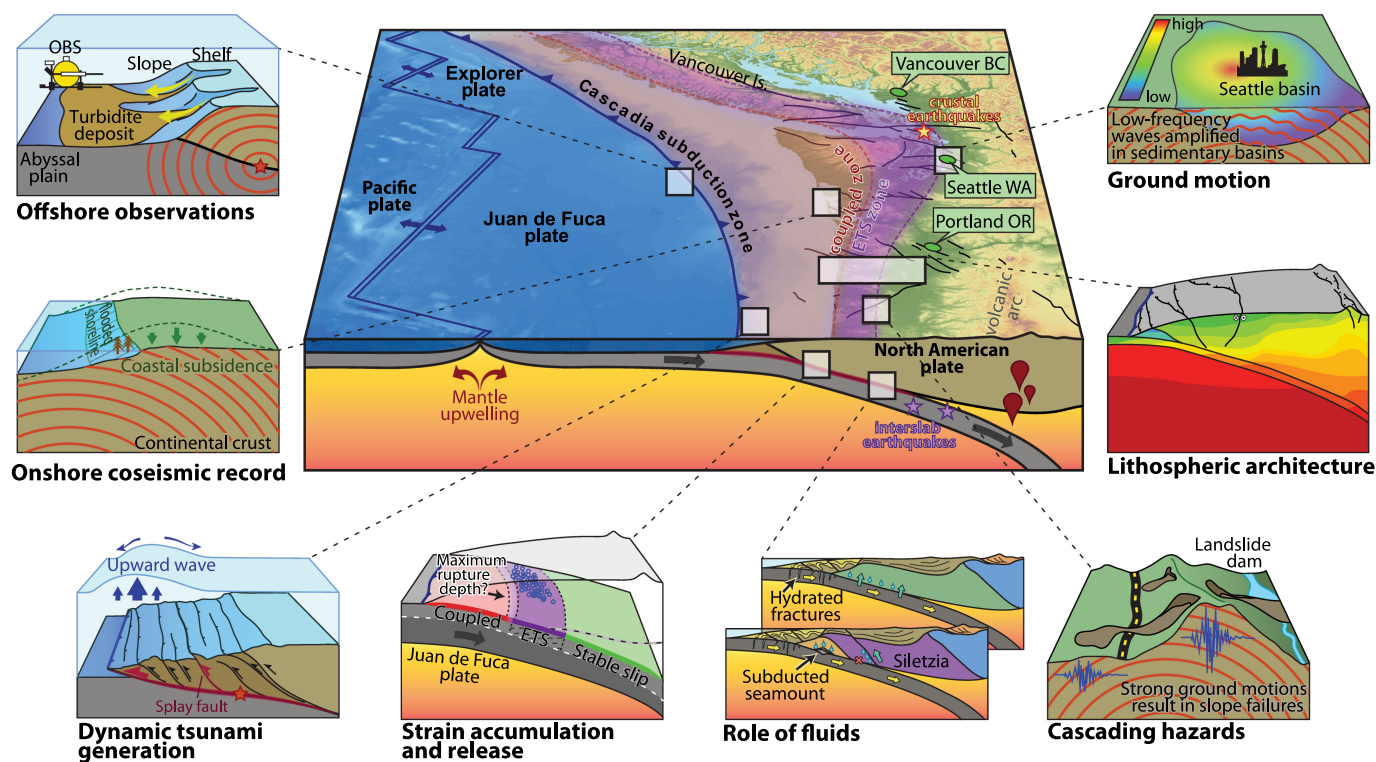
(2026). Henceforth, we focus on the Science Planning pillar of CRESCENT, which is organized into five working groups (WGs, Fig. 2), each responsible for producing community products, tools, and databases intended for use across CRESCENT and by the broader scientific community. These WGs focus on developing community velocity and fault models (CMV and CFM), conducting dynamic rupture and earthquake cycle simulations, quantifying the regional stress budget and coupling along major tectonic structures, and building and expanding world-class paleoseismic databases (Fig. 2). In addition, CRESCENT supports four special interest groups (SIGs) that explore emerging research frontiers and technologies in earthquake science (Fig. 2). The scientific WGs and SIGs are detailed in following sections of this article.

CRESCENT resources and activities are geared toward supporting individual goals of each of the three pillars (Fig. 2). These resources include a dedicated cyberinfrastructure and development team for creating tools to visualize and disseminate

research products, creating open-source software that facilitates community participation in research, and support for developing and documenting center research products so that CRESCENT science is transparent and reproducible (Wilkinson *et al.*, 2016). We note that the scope of the challenge is much larger than what CRESCENT alone can tackle, so that the center also includes activities meant to foster nascent ideas outside of the core mission of the pillars, such as the seed grant program that has two objectives: to increase the breadth of the community involved in CSZ research and to expand the scope of scientific questions related to the center's objectives. A request for proposals is typically released each fall (see Data and Resources).

Systems Level Approach to Subduction Zone Geohazards

Although the CSZ has been the subject of intense scientific scrutiny, there are many areas where foundational research



(Fig. 3) is still necessary, and CRESCENT's WGs and SIGs were designed to address this need. The following is a brief overview of the outstanding major science questions related to the CSZ motivating the WGs and SIGs and summaries of the activities of each.

State of knowledge

Cascadia is a 1200 km long subduction zone that accommodates 30–40 mm/yr of relative motion between the Juan de Fuca and North American plates (Fig. 4) (DeMets *et al.*, 2010). Paleoseismic studies find evidence for 14 full-margin ruptures in the last 7700 yr, indicating that recurrence intervals average to 550 yr for these M 9+ earthquakes (Atwater and Hemphill-Haley, 1997; Goldfinger *et al.*, 2012; Walton *et al.*, 2021). There is also abundant evidence for partial ruptures in onshore and offshore paleoseismic data where studies show that earthquakes occur more frequently in southern Cascadia (Nelson *et al.*, 2006; Goldfinger *et al.*, 2017; Walton *et al.*, 2021). Modern estimates of strain accumulation from space geodesy (Schmalzle *et al.*, 2014; Li *et al.*, 2018) indicate that plate coupling varies along strike, suggesting that the plate boundary has considerable along-strike variability (Fig. 5). The margin is often divided into three potential segments, with the northern and southern segments characterized by rapid geodetic and geomorphic uplift rates, rapid erosion rates, high coseismic subsidence during great megathrust ruptures, shallower slab dip angles, and increased plate coupling as compared with the central segment (e.g., Schmalzle *et al.*, 2014; Figs. 4 and 5). However, there is still considerable debate on the overall patchiness, timing, and spatial location of segmentation and

Figure 3. Foundational research foci of CRESCENT and of Cascadia subduction zone (CSZ) earthquake hazards. Modified from Walton *et al.* (2021). The color version of this figure is available only in the electronic edition.

megathrust coupling along the plate interface (Nelson *et al.*, 2006; Wang *et al.*, 2013; Hutchinson and Clague, 2017; Melgar, 2021).

One characteristic of the CSZ that sets it apart from all other global subduction systems is the apparent dearth of everyday plate-boundary seismicity recorded in the instrumental era. The megathrust is anomalously quiet, with only a few isolated clusters of earthquakes (e.g., Tréhu *et al.*, 2015; Bostock *et al.*, 2019). Damaging events have originated in either the shallow crust (e.g., Scotts Mills M 5.6 earthquake in 1993) or deep from within the subducting slab (i.e., intraplate), the most recent being the 2001 M 6.8 Nisqually earthquake (Ichinose *et al.*, 2004) beneath southern Puget Sound. Despite the reduced rates of interplate earthquakes, the Cascadia megathrust is rich in diverse types of seismic and aseismic activity. Geodetic and seismic data have revealed that at depths of 25–40 km, the plate-boundary slips regularly in slow-slip events (SSEs, Rogers and Dragert, 2003), which also produce tremor. This area is often referred to as the episodic tremor and slip (ETS) zone. Fluids appear to be intimately linked to the distribution of shallow crustal seismicity and SSEs, providing the opportunity to further understand the relationship between fluids and seismogenesis (Bostock *et al.*, 2019). Furthermore, paleoseismic research in the past 20 yr indicates that the hazard from

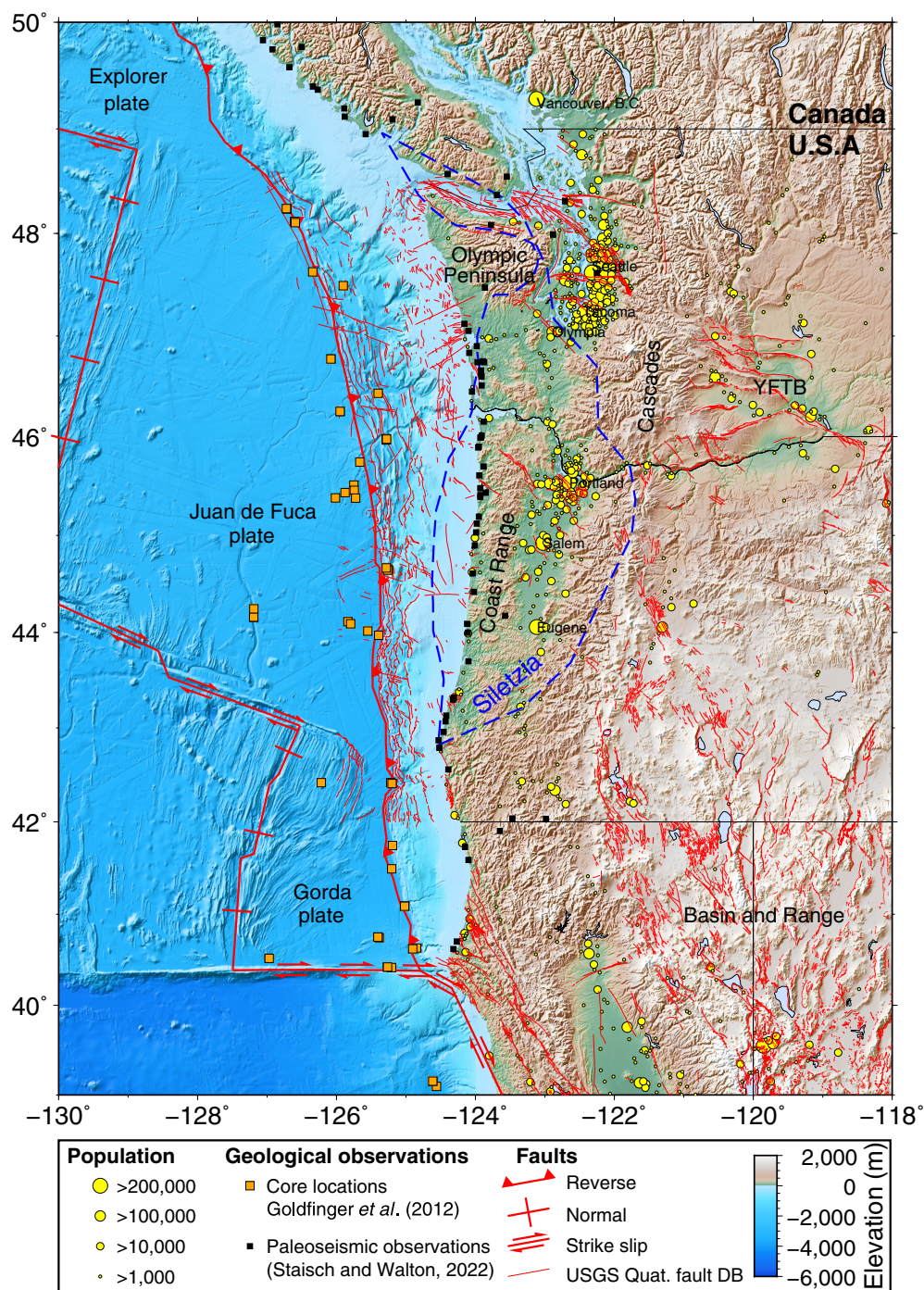


Figure 4. Geological context of the Pacific Northwest showing: geodetic vectors relative to stable North America (orange arrows; DeMets *et al.*, 2010; DeSantos *et al.*, 2025); onshore paleoseismic observation locations (Staisch and Walton, 2022); offshore turbidite cores (Goldfinger *et al.*, 2012); the trench from Slab2 (Hayes *et al.*, 2018); and plate boundary and upper crustal fault structures (bold and thin red lines, respectively) (U.S. Geological Survey, 2020). A revised community fault model (CFM) could include an effort to digitize faults from the Mendocino triple junction to the California–Oregon border. Background shaded relief and bathymetric maps are sourced from Becker *et al.* (2009). YFTB, Yakima fold and thrust belt. The color version of this figure is available only in the electronic edition.

upper-plate faults underlying the Puget Lowland (e.g., the Seattle fault, Black *et al.*, 2023), the Willamette Valley (Horst *et al.*, 2021), and other structures capable of hosting $M \sim 7$

in the last ~ 30 yr, yet a complete understanding of its associated hazards remains a scientific and societal challenge. Working in partnership with regional hazard assessment agencies (Sahakian

events is substantial and places these densely populated urban regions (Figs. 1 and 4) at great risk (Nelson *et al.*, 2014; Frankel *et al.*, 2015).

The CSZ is a source of earthquake and tsunami hazards for the Pacific Northwest. Estimates of strain accumulation combined with the 325 years since the last $M 9$ event suggest that the megathrust has accrued enough slip deficit to produce anywhere from an $M 8.9$ to a 9.1 earthquake (Chapman and Melbourne, 2009). Such large events would result in widespread, strong ground motions for which likelihoods and details are still poorly understood. For example, sedimentary basins, where most of the region's population resides, will intensify and extend shaking duration by often unknown amounts (Wirth *et al.*, 2022). In addition, there is the potential for catastrophic and more impulsive ground shaking from other earthquake sources such as intraplate events. In addition, in the offshore portion of the system, strain accumulation and fault architecture, particularly in the near-trench region, is not well known either (e.g., Wang and Tréhu, 2016). As a result of this limited knowledge, our ability to estimate tsunami impacts remains only rudimentary even if geologic and historical data indicate that inundation will be widespread and quite likely catastrophic (Wood *et al.*, 2015).

CRESCENT's WGs

Understanding of the tectonics, structure, and mechanics of the CSZ has increased significantly

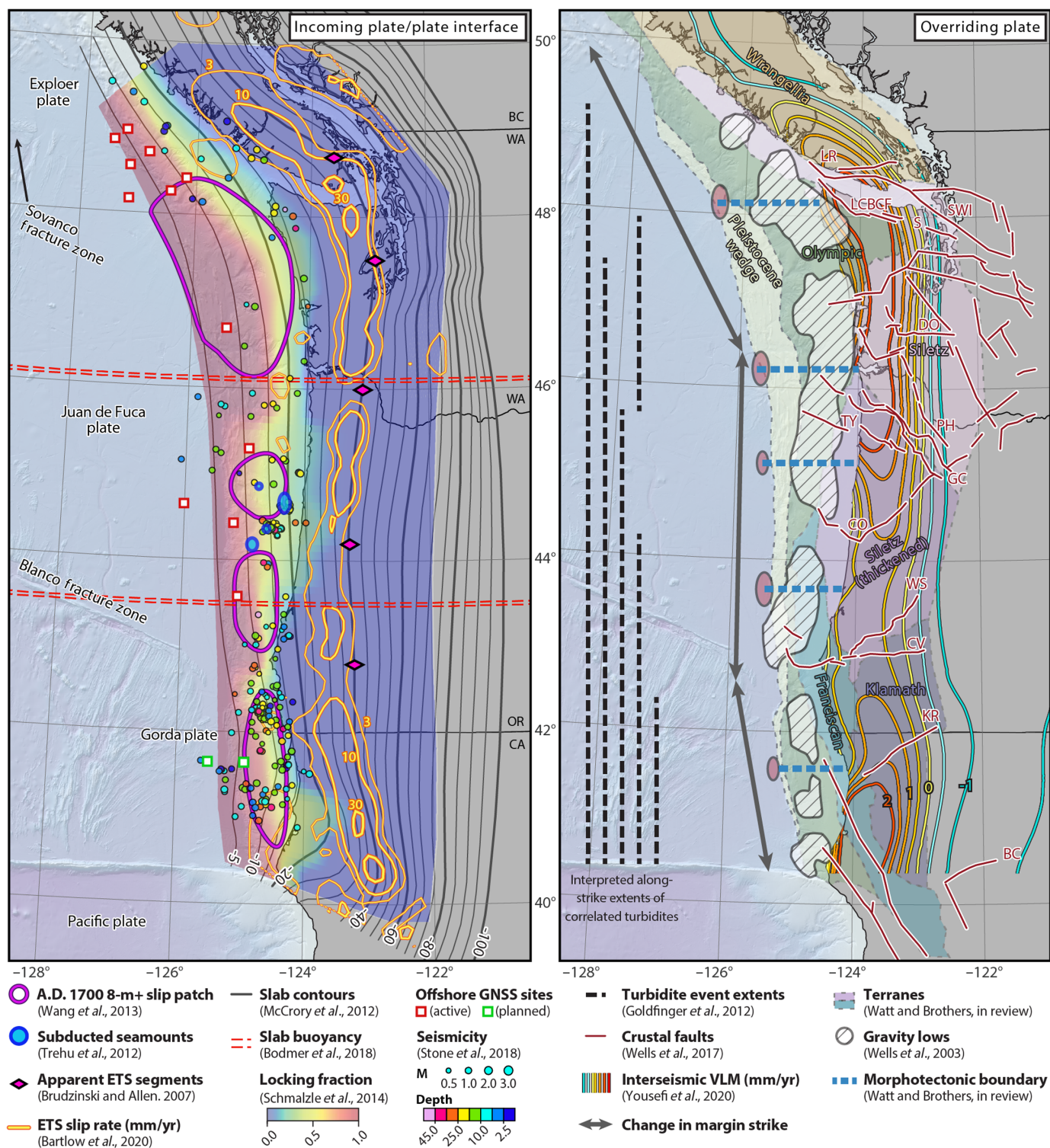


Figure 5. Geophysical and geologic datasets illustrating along-strike variability of the Cascadia subduction zone, adapted from Walton et al. (2021). The left panel highlights time-averaged episodic tremor and slip (ETS) slip-rate contours (Bartlow, 2020) and seismicity from Stone et al. (2018), with dense clusters near 44.3° and 44.6° coinciding with subducted seamounts inferred from magnetic and

gravity data (Trèhu et al., 2012). The right panel depicts heterogeneities on the overriding plate, where morphotectonic zones lack sharp boundaries (Watt and Brothers, 2021). Faults and lineaments are labeled (LR, S, SWI, LCBCF, DO, CR, GC, TY, CO, WS, CV, KR, PH, and BC). Bathymetric base map from Wong and Grim (2015). GNSS, Global Navigation Satellite System. The color version of this figure is available only in the electronic edition.

et al., 2026), CRESCENT's WGs consist of scientists, engineers, and educators who develop tools and products that can enable transformational basic science research and increase the effects science has on hazards, risk, and resilience. Some WGs focus on synthesis and integration of information into community models so that products are relevant to basic and applied science. Others will develop tools to advance the understanding of subduction zone processes at the CSZ. Each WG gathers frequently to ensure progress on their respective charges. WGs also organize workshops on topics of widespread interest to the scientific community, such as subduction zone fluids and tsunamis. Each WG will also organize technical short courses to further CRESCENT's workforce development goals. Finally, WGs regularly engage with one another to collectively navigate interdependency and overall consistency between their products. The WGs have broad community buy-in (see center website for participants list, see [Data and Resources](#)) and a rotating membership that aims to represent a cross-section of the community. A mailing list managed through that website is open for anyone to join and used to keep community members apprised of events and ways to engage with and participate in CRESCENT. In the sections that follow, we describe each of the five WGs.

Shoreline-crossing community velocity model. Accurate velocity structure models at a variety of scales along the CSZ can advance understanding of large- and small-scale features and processes in the region. They can also serve as foundational datasets for related basic and applied science activities. In pursuit of a more comprehensive understanding of large-scale processes, several questions remain. For example, what are the effects of the CSZ, bracketed by major active transform boundaries to the north and south (Fig. 4), on the heterogeneity of mantle flow beneath the subducting plate (e.g., [Zandt and Humphreys, 2008](#); [Bodmer *et al.*, 2018](#))? In turn, what influence does this upper mantle structure and asthenospheric flow have on the shape of the slab and on the consequent stress state within the slab? Moreover, what is the interaction between variable along-margin seismic velocities and tectonic behavior, and how does this impact future earthquake hazards? Spatial correlation between variations in down-dip coupling, tremor density, and fluid distribution suggests that geologic and structural controls on the interface properties of the megathrust are considerable ([Bodmer *et al.*, 2018](#); [Delph *et al.*, 2018, 2021](#)). On the other hand, seismic tomography reveals low-velocity anomalies beneath the fore-arc slab in the northern and southern parts of the CSZ, which are inferred to be regions of partial melt, resulting from localized upwellings, and regions of positive mantle buoyancy ([Bodmer *et al.*, 2018](#)). The cause-and-effect relationship between velocities, densities, fluids, and geodynamics remains an outstanding problem that has implications for understanding the occurrence of full-margin versus segmented ruptures, as well

as seismogenic width and resulting onshore ground motions ([Wirth and Frankel, 2019](#); [Melgar *et al.*, 2022](#)).

A first step to support advancing our understanding of these topics and the underlying science is constructing and maintaining a unified CVM representative of the CSZ and surroundings, containing multiscale properties throughout the lithosphere. In addition to controls on large megathrust sources, physical properties also play a key role in the modulation and amplification of the seismic wavefield. The overriding plate and crust will form the wavefield's path from megathrust source to surface, but we have yet to fully image and constrain large low-velocity structures at those depths and their focusing effects on wave propagation ([Abers, 2005](#); [Furumura, 2005](#); [Mann and Abers, 2020](#); [Sahakian *et al.*, 2018](#)). Near the surface, much work on the effects of shallow structure has focused on the likely amplification of ground motion in the Seattle basin ([Olsen *et al.*, 2008](#); [Wirth and Frankel, 2019](#); [Roten *et al.*, 2020](#); [Thompson *et al.*, 2020](#); [Rekoske *et al.*, 2022](#)), but other basins remain less well studied such as those containing the Portland and Tualatin metropolitan areas ([Frankel and Grant, 2021](#)), and the Willamette Valley ([Silva *et al.*, 1998](#)). Even more poorly characterized are the contacts between these basins and the surrounding Cascadian topography. Basin edges are major amplifiers of ground motion (e.g., [Brissaud *et al.*, 2020](#)) where better constraints could improve hazard and risk estimates.

The CVM WG will work with the community to gather, combine, and validate existing velocity models and metadata for the CSZ, collaborate with the U.S. Geological Survey (USGS) to build upon the [Stephenson *et al.* \(2017\)](#) model, and develop a robust CVM. The development of a CVM involves several key steps to enhance understanding of the outer fore-arc region. First, the group will compile existing structural and velocity models, integrating data from receiver function studies, regional-scale tomography, crustal studies, and high-resolution marine and onshore-offshore experiments (e.g., [Carbotte *et al.*, 2024](#)). Validation frameworks and gridded information on input sources will support misfit analyses and earthquake simulations. The CVM WG will document methods used to construct the model, model results, uncertainties, and recommendations for future iterations. Community workshops and technical courses led by the WG will focus on CVM development, use, and validation. Finally, the CVM will be ported to commonly used file formats, ensuring long-term accessibility by a broad community of users.

Shoreline-crossing CFM. Beyond the megathrust, crustal earthquakes in the North American upper plate and the Juan de Fuca lower plate are some of the most poorly constrained potential earthquake sources in Cascadia. Both upper plate and intraslab noninterface earthquakes, and their causative structures, are frequently near population centers (Fig. 4; [Frankel *et al.*, 2015](#)) and have potential for substantial coseismic and cascading hazards. Intraplate slab and shallow upper-plate earthquakes

dominate the U.S. National Seismic Hazard Model in this region (Petersen *et al.*, 2020), with a Nisqually-like rupture on the down-going slab considered as one of the most likely future damaging events in the region.

Development of a CFM WG will serve at least three critical functions. First, it serves as a foundation of fault geometric characteristics and event histories that are inputs into characterization of upper-plate hazards (Wells and Coppersmith, 1994; Barnett *et al.*, 2010; Biasi and Wesnousky, 2016). Paleoseismic investigations in the northern Puget Lowland (Nelson *et al.*, 2014; Personius *et al.*, 2014; Schermer *et al.*, 2020; and others) indicate that shaking and hazard from a regional shallow upper-plate earthquake is likely to be similar to that of a megathrust M 9 CSZ event. A substantial amount of the regional population is concentrated in the Puget–Willamette Lowland, which indicates that upper-plate faults likely dominate the risk profile. Upper-plate earthquake ruptures at other subduction plate boundaries have proven to be complex in their magnitude and frequency content, are spatially distributed, and consequently, are highly destructive (e.g., Hamling *et al.*, 2017; West *et al.*, 2020). Second, stress modeling studies demonstrate that paleoseismology and well-constrained fault topology in 3D are necessary prerequisites to understand fault interaction (Sherrod and Gomberg, 2014; Delano *et al.*, 2017; Duckworth *et al.*, 2021). Models of earthquake triggering indicate that stress transfer modulates the behavior of faults on earthquake and multi-earthquake timescales (Stein *et al.*, 1997; Goldfinger *et al.*, 2008). For example, it has been posited that upper-plate faults interact with the Cascadia megathrust, but the issue remains unresolved and is of fundamental importance (Sherrod and Gomberg, 2014; Goldfinger *et al.*, 2025). The 1992 M 7.1 Cape Mendocino event, potentially the last large event to occur on the subduction interface, had a locally recorded acceleration of 2g (Oglesby and Archuleta, 1997). Relocations of slab seismicity and aftershocks also allow for an alternative view in which the mainshock occurred on a shallow upper-plate thrust above the plate boundary, so its exact relation to the megathrust remains debated (Oppenheimer *et al.*, 1993; Murray *et al.*, 1996; Guo *et al.*, 2021). In addition, splay faults in the accretionary prism offshore may strongly influence the characteristics of both near- and far-field tsunamis (Priest *et al.*, 2010; Wang and Tréhu, 2016; Aslam *et al.*, 2021; Walton *et al.*, 2021; Watt and Brothers, 2021). The CFM WG will use new (i.e., Carbotte *et al.*, 2024) and legacy geophysical data to provide detailed geometrical constraints on these Quaternary active structures that extend offshore.

The CFM WG fault model building efforts will be conducted in partnership with the USGS NSHM group to establish fault quality standards for inclusion in the CFM. The working group will synthesize fault system information from the NSHM (Fig. 1), along with historical and recent studies of onshore and offshore faults (Figs. 4 and 5), and incorporate active-fault characteristics such as event chronology, slip rates, earthquake magnitudes, and timing of the last known events. The eventual

database will provide detailed information on fault locations, topology, and attributes like geodetic block correspondence and historical earthquake parameters where available. The CFM group will also lead technical short courses focused on identifying fault interaction, coupling, and fault behavior across timescales.

Cascadia paleoseismology. Paleoseismic studies along subduction zones and upper crustal fault systems provide insight into the long-term fault behavior and the response of the Earth's surface to fault displacement, which provide boundary conditions for geodetic models, place first-order constraints on rupture models, and inform regional seismic hazard assessments (Fig. 1, Field *et al.*, 2015; Morell *et al.*, 2020). The coastal and offshore paleoseismic datasets along the Cascadia subduction zone are some of the longest and most detailed records of megathrust events globally (Walton *et al.*, 2021); however, uncertainties remain on the timing of past events, synchronicity of evidence at multiple sites, and how variable CSZ earthquake hazards are based on the paleoearthquake records (Nelson, 1992; Melgar, 2021; Nelson *et al.*, 2021; Staisch, 2024).

Within tidal wetlands, sharp stratigraphic contacts consisting of organic-rich soils overlain by minerogenic tidal mud represent sudden coseismic subsidence of the coast (Nelson *et al.*, 1996). At some sites, anomalous sand and silt layers signaling high-energy tsunami inundation, sediment transport, and deposition are found at the soil–mud contacts (Witter *et al.*, 2013). Recent advances in statistical methods for quantifying coastal subsidence (Milker *et al.*, 2016; Padgett *et al.*, 2021) and in using detailed tsunami sand mapping to identify past event inundation (Bosnic *et al.*, 2021; La Selle *et al.*, 2024; Small *et al.*, 2025) have improved our understanding of site-specific hazards and exposed along-strike variability in past events (Wang *et al.*, 2003; Kemp *et al.*, 2018; Wirth and Frankel, 2019). At present, detailed mapping of coastal stratigraphy and sedimentology, along with high-resolution microfossil-based relative sea-level reconstructions using diatoms and foraminifera, produce the most accurate and precise estimates of vertical deformation during coseismic and interseismic land-level change and tsunami inundation estimates (Horton *et al.*, 2000). Using these techniques, the coastal impact from past great ($M_w > 8$) earthquakes that reach as far back as 7 ka have been reconstructed at sites spanning the CSZ (e.g., Atwater *et al.*, 1995; Atwater and Hemphill-Haley, 1997; Witter *et al.*, 2003; Nelson *et al.*, 2006, 2021). The application of these state-of-the-art techniques is currently spatially and temporally limited in Cascadia. The Cascadia Paleoseismology (CPAL) WG is poised to contribute to the CRESCENT community by expanding these techniques spatially and temporally.

Despite the CSZ having a relatively comprehensive paleoseismic catalog, records are variable in their stratigraphic continuity and length, have varied age-control quality, and often lack quantitative estimates of coseismic land-level change and detailed tsunami deposit mapping (Nelson *et al.*, 2021). These

data gaps allow for many nonunique rupture scenarios that all fit the paleoseismic constraints and thus preclude refining hazard uncertainty (Walton *et al.*, 2021). In addition to onshore paleoseismic data, offshore turbidite datasets have previously been used to complement coastal CSZ paleoseismology (e.g., Goldfinger *et al.*, 2012, 2017) and have been robustly applied along other subduction zone margins to identify event synchronicity (e.g., Pizer *et al.*, 2024). Recent efforts focused on better constraining the precision and accuracy of age control and correlation of offshore paleoseismic data in Cascadia (Staisch, 2024; Nieminski *et al.*, 2025) highlight that high-resolution offshore paleoseismology and refined age analysis may resolve important questions on past earthquake frequency and rupture length. Although outside the scope of CPAL's efforts, existing and upcoming offshore paleoseismic datasets will be incorporated and evaluated alongside onshore datasets for synthesis and interpretation.

CPAL aims to characterize the spatial and temporal patterns of coseismic land-level change and tsunami inundation from past CSZ earthquakes to inform kinematic and dynamic rupture models of past and future events (including upper plate, megathrust, and intraplate). To achieve this goal, CPAL will build a community of practice in collaboration between geologists and geophysicists with the shared objective of integrating paleoseismic data as constraints into models. CPAL will leverage the comprehensive paleoseismic databases (e.g., land-level change estimates, earthquake chronologies, and tsunami inundation extents) recently created by the USGS Powell Center Cascadia Earthquake Hazards group to target data gaps for new field and laboratory work (Staisch, 2024). CPAL members will visit coastal sites spanning northern California to southern Canada to generate new quantitative land-level change estimates, refine earthquake chronologies, and map the inland extent of tsunami deposits in areas where limited or imprecise data have previously made it difficult to validate models of dynamic rupture, tsunamigenesis, and the earthquake cycle. This WG will incorporate the new paleoseismic data into an updated comprehensive online repository together with the existing USGS dataset. To facilitate quantitative coastal land-level change analyses, the WG will develop a community-built microfossil taxonomy and photo database and a related website to support more accessible and standardized microfossil analysis. Fieldwork and laboratory analyses will also target coastal sites with known active upper-plate structures where coseismic land-level change estimates may record deformation on shallow crustal structures, ultimately leading to a better understanding of megathrust-upper-plate fault coupling.

Dynamic rupture, earthquake cycle, and tsunami modeling. Assessing the contribution of processes and physical properties to Cascadia rupture scenarios can enhance understanding of megathrust rupture behaviors, which are required to produce accurate forecasts of future earthquake

and tsunami hazards (e.g., Fig. 1). Factors that govern the nature of rupture propagation and eventual arrest during megathrust events include the amount of accumulated strain, the geometry and roughness of the fault plane, the rheologic properties of the materials present in and surrounding the fault zone, the pore-fluid pressure distribution, and the ambient temperature distribution.

In the CSZ, along-strike variability has been proposed for the megathrust based on upper-plate geologic properties (Wells *et al.*, 2014), plate morphology and geometry (e.g., Bletery *et al.*, 2017; Bodmer *et al.*, 2018), lower plate properties (e.g., Schmalzle *et al.*, 2014), evidence for along-strike differences in coastal coseismic subsidence (e.g., Wang *et al.*, 2013), and observations of differences in episodic tremor and slip events along the margin (e.g., Brudzinski and Allen, 2007). How specifically these variations influence rupture propagation is an open question. In addition to this along-strike variability, thermopetrologic structure exerts a first-order control on the up-dip and down-dip limits of rupture, with the seismogenic zone bounded by clay dehydration reactions up-dip and by the transition to a warm, potentially serpentinized mantle wedge down-dip (Hyndman *et al.*, 1997; Wang and Tréhu, 2016; Wang, 2024). This down-dip limit, especially whether rupture extends into or past it, has important implications for ground motions in all the major population centers in the Pacific Northwest (e.g., Wirth and Frankel, 2019; Melgar *et al.*, 2022). Geodetic observations indicate that there is some strain accumulation just above the ETS region (Fig. 5), yet it has hosted only one long-duration SSE (Nguyen and Schmidt, 2021); it is still unknown how strain accumulation just above the ETS zone potentially contributes to coseismic rupture. Further down-dip, in the ETS region, seismic imaging, tremor, and low-frequency earthquake studies indicate the presence of fluids at nearly lithostatic pore-fluid pressures, and that faults in these areas exist under very low effective stress (e.g., Rubinstein *et al.*, 2007; Audet *et al.*, 2009; Houston *et al.*, 2011; Royer *et al.*, 2015; Delph *et al.*, 2018; Delph *et al.*, 2021). Stress state, fault architecture, and fluid pressure are first-order controls on rupture propagation, so enhancing our understanding of not only the fluid distribution along the megathrust, particularly the ETS region, but also the architecture of faults hosting ETS processes could help better discern associated rupture behavior and the resulting ground motions.

The dynamic rupture, earthquake cycle, and tsunami modeling (DET) WG will focus on investigating these questions. The utility and relevance of their models hinge on assumptions and deterministic inputs: structure and geometry, material properties and rheology (elastic and inelastic), stresses and pore pressure, fault rheology and friction, and other processes governing fault strength evolution (Harris *et al.*, 2018; Erickson *et al.*, 2020). They will also require geological inputs from other WGs, including onshore-offshore fault and velocity models (CFM and CVM) and observations of coseismic coastal

subsidence (CPAL). Unlike single-event dynamic rupture simulations, fully 3D multiearthquake cycle modeling is less mature but can increase understanding of longer term dynamics, multisegment rupture probabilities, and slip behavior in the gap between the locked seismogenic and ETS zones, which represent a distinct rheological domain (e.g., [Gao and Wang, 2017](#)). To account for stress redistribution and connect to geodetic and related constraints on fault coupling and slip history ([Gallovič et al., 2019](#); [Hirahara and Nishikiori, 2019](#); [Li and Liu, 2021](#)), this group will model the earthquake cycle time-scale of hundreds to thousands of years, including aseismic and slow slip, as well as past earthquakes, and connect with the CPAL WG to validate these models with long-term paleoseismology proxies.

The DET WG will develop models of the CSZ that further our knowledge of basic processes such as earthquake rupture dynamics, multisegment rupture probabilities, shallow deformation and tsunamigenesis, fluid production and migration, and deep deformation and SSEs. SeisSol is an open-source 3D code designed for modeling dynamic ruptures, ground motion, and tsunamis in the coupled solid Earth-ocean system (e.g., [Ramos et al., 2021](#); [Ulrich et al., 2022](#)). It has demonstrated high performance on advanced supercomputers ([Krenz et al., 2021](#)) and will be used by DET to model scenario events in the CSZ. These models will integrate constraints on material structure and faults provided by other WGs, with a special emphasis on shallow rupture behavior, distributed inelastic sediment deformation, slip on splay faults, and interactions with upper-plate faults. The group will produce SeisSol input files tailored to Cascadia for dynamic rupture and tsunami generation modeling, making them available for community research. DET will also conduct verification exercises for earthquake cycle modeling codes, addressing megathrust-specific challenges and gradually incorporating processes such as SSEs, with validation using data products like SSE catalogs. DET will also develop advanced, open-source 3D earthquake cycle codes specific to Cascadia, incorporating realistic structures, temperature-dependent viscoelasticity, fluid transport, pore-pressure evolution, and slow slip, guided by multidisciplinary discussions at CRESCENT workshops.

Coupling, seismicity, and slow slip. Both Global Navigation Satellite System (GNSS) and other geodetic estimates of strain accumulation indicate that interplate coupling between the Juan de Fuca and North American plates varies considerably along strike (Fig. 5), supporting a model in which the CSZ is potentially segmented into distinct northern, central, and southern sections. A notable spatial correlation between the down-dip limit coupling, tremor density, and fluid distribution inferred from electrical resistivity studies suggests that these fluids play a key role in putative segmentation ([Egbert et al., 2022](#)). However, major uncertainties remain regarding the degree of coupling patchiness within segments,

the precise locations of segment boundaries, and the persistence of those boundaries over multiple earthquake cycles ([Nelson et al., 2006](#); [Wang et al., 2013](#); [Hutchinson and Clague, 2017](#); [Melgar, 2021](#)). In addition, viscoelastic rheology of the fore-arc and mantle wedge strongly influences how interplate stress is accumulated and redistributed through the cycle, so interpretations of coupling patterns and segmentation from geodetic data must be framed within viscoelastic Earth models (e.g., [Wang and Tréhu, 2016](#)). Constraining both the exact heterogeneity of coupling and the nature of potential segment boundaries can aid in assessment of Cascadia hazards. In other subduction zones, such as Ecuador and Japan, regions of strong interseismic coupling have been shown to correlate with the eventual coseismic slip during large megathrust earthquakes ([Nocquet et al., 2017](#)). Coupling also potentially influences key rupture characteristics that control seismic hazard, including rise time, stress drop, and slip distribution, which collectively affect high-frequency ground motion. Whether seismogenic rupture can propagate into the ETS zone (Fig. 5) has direct implications for the major population centers of the Puget Sound and Willamette Valley, which lie directly above it ([Chapman and Melbourne, 2009](#); [Melgar et al., 2022](#)). Because slow slip and associated nonvolcanic tremor (e.g., [Obara, 2002](#)) perturb the geodetically measured deformation field, seismicity, coupling, and transient slip must be jointly modeled to accurately assess hazards.

The coupling, slow slip, and seismicity (C3S) WG will develop a comprehensive, time-dependent model of strain accumulation and release in Cascadia. C3S will work to develop an interseismic velocity field based on the best available 3D rheological structure of the CSZ and constrained by Global Positioning System/GNSS, Interferometric Synthetic Aperture Radar, tide gauge data, and other measures of the surface deformation field. Initial work will focus on elastic deformation, and the WG will also make progress toward developing a viscoelastic model in later years. The WG will use this surface velocity model in conjunction with a block model of Cascadia to simultaneously estimate deformation rates at block boundaries and interseismic strain accumulation on the megathrust. Once established, the WG will develop a seismogeodetic detection framework to identify meaningful departures from this velocity field indicative of SSEs, changes in coupling, or other transient deformation processes. Slip transients will be characterized using kinematic slip inversions when possible. C3S will also leverage new deep learning tools to create a high-resolution seismicity catalog for Cascadia derived from both onshore and offshore legacy seismic data. This catalog will include both traditional seismicity and nontraditional seismicity such as low-frequency and very-low-frequency earthquakes. C3S will compare distributions of seismicity, along with geodetically inferred slip, to explore interactions between different strain release mechanisms and any triggering therein. Moreover, a key goal for the catalog is to integrate the improved 3D velocity models from the CVM WG to

facilitate accurate earthquake locations and better understand the relationship between the seismicity and the faults identified by the CFM WG.

CRESCENT's special interest groups (SIGs)

CRESCENT's SIGs will pay special attention to frontier science that will help steer center activities toward future hazards research. SIGs' objectives center around areas that may eventually become fully formed WGs in CRESCENT.

Offshore geophysical observations. The surface expression of the CSZ plate margin is offshore, as is most of the coupled zone where strain is accumulating (Figs. 1 and 5). Furthermore, the long-term deformation and structure of the marine fore-arc (e.g., distribution and size of splay faults) may reflect the integrated frequency and size of megathrust earthquakes (Rosenau *et al.*, 2009) and influence and act as a backstop to future tsunami sources (e.g., Booth-Rea *et al.*, 2008; Han *et al.*, 2017; Watt and Brothers, 2021; Lucas *et al.*, 2021). Enhancing the quality and quantity of offshore geophysical experiments in Cascadia (e.g., Toomey *et al.*, 2014) can support and advance CRESCENT science goals. In response, the Offshore Observations SIG will gather broad community input on observational needs and priorities and will identify specific areas for accelerated progress through coordination and the development of collaborations that link the academic community, federal and state agencies, private companies, and international partners. Specific tasks include (1) coordinating nascent efforts to evaluate offshore distributed acoustic sensing; (2) planning for expanded geodetic observations to measure both secular strain and transient fault slip; (3) developing plans to improve geophysical instrumentation on the nodes of the Ocean Observatories Initiative (OOI) Regional Cabled Array (RCA) off central Oregon; (4) seeking opportunities to expand high-resolution seafloor mapping using autonomous vehicles; (5) expanding the OOI RCA to support research on early warning technologies and a prototype offshore early warning system; (6) obtaining multichannel seismic data in less well-sampled regions such as the Washington margin; and (7) exploring collaborations with the physical oceanographic community to improve the resolution of seafloor geodetic data.

Frontiers in ground-motion modeling. Translating fundamental scientific advances in the CSZ to their implications for strong ground motion in the region is key to improving our understanding of seismic hazards, their subsequent risks and impacts. This requires empirical input, high-end computing and modeling, and validation with geologic proxies. It also involves time-dependent monitoring of the shallow subsurface in Cascadia and its nonlinear behavior (Boore and Joyner, 1997; TenCate *et al.*, 2004; Choi and Stewart, 2005) as it continuously undergoes modifications due to tectonic, environmental, and anthropogenic forcings (Richter *et al.*, 2014; St. Clair *et al.*, 2015; Viens *et al.*, 2018). Recent years have seen

an influx of new data that can help in these efforts and enhance the current Stephenson *et al.* (2017) velocity model (e.g., Carbotte *et al.*, 2024), especially at shallow depths. The ground-motion modeling (GMM) SIG will be a collaborative effort charged with improving our understanding of ground motion by both empirical and physics-based means. Specifically, GMM will (1) collaborate closely with the USGS and others carrying out research in the sphere of empirical ground-motion estimation and high-performance propagation models; (2) work closely with the DET and CVM WGs to lay down the foundation for dynamic ruptures and velocity models to be applied to understanding strong motions; (3) host and facilitate bi-monthly to quarterly meetings between workers and stakeholders in the field; and (4) align itself with stakeholders (i.e., academic engineering community, federal and state agencies, the Cascadia Lifelines Program (CLiP), and many more) to provide estimates of ground motion.

Liquefaction, landslides, and ground failure. Near-surface properties and processes in Cascadia are not only key indicators of ground motions from moderate to large earthquakes but also, intrinsically, impact all cascading hazards from such events (Unjoh *et al.*, 2012). There is potential for landslides, liquefaction, lateral spreading, ground failure, and so forth, in Cascadia where the combination of high-relief landscapes adjacent to either broad valley lowlands or coastal plains plays host to multiple near-surface or at-surface hazards. The central goal of the SIG is shallow hazards and to translate related CRESCENT outputs into societally relevant products. This can only be done in close collaboration with federal and state agencies (California Geological Survey, Oregon Department of Geology and Mineral Industries, and Washington State Department of Natural Resources). In the absence of such efforts, planning for the direct and indirect impacts of a CSZ megathrust rupture is speculative, and could hinder strategic community resilience and recovery planning. To make progress on these issues, this SIG will (1) host and facilitate workshops with near-surface hazards specialists; (2) establish and maintain an interdisciplinary cascading hazards community; and (3) work closely with the WGs (especially CVM and DET) to ensure their products accurately reflect the current state of knowledge on near-surface and cascading hazards. This SIG will also align itself (4) with the societal resilience and applied science efforts in CRESCENT as well as (5) other major science-to-society pipelines (e.g., CLiP, Cascadia Coastlines and Peoples [CoPes] Hub) to enhance community engagement.

Subduction zone fluids. Fluids make up only a small fraction of the CSZ volume but are a major (if not the primary) trigger and driver of geohazards in the region. Fluid presence, pore pressure, and migration within fault zones influence and trigger slip behaviors over a wide-magnitude range through both mechanical and geochemical processes (e.g., Wells *et al.*, 2003).

Along the subduction interface, these fluids are produced by pore-space compaction, diagenesis, and metamorphic reactions, suggesting a causal relationship between chemical processes, fluids, and plate-boundary slip behaviors (e.g., [Condit et al., 2022](#)). Through flux melting in the mantle wedge, fluids are also central to the existence and persistent threat of explosive volcanic eruptions (e.g., [McGary et al., 2014](#); [Bedrosian et al., 2018](#)). A first step could be creating a unified database and enhancing understanding of CSZ fluids. The subduction zone fluids SIG will lead that effort and consolidate direct measurements (e.g., borehole) and indirect proxies (e.g., electrical conductivity, Poisson's ratios, spatiotemporal seismicity and tremor distributions, and studies on exhumed rock) of fluids and work toward creation of a fluid content model for the CSZ that is empirically, thermomechanically, and chemically consistent. The fluids SIG's specific goals are (1) consolidating direct fluid observations and proxies of subduction zone fluids in Cascadia; (2) translating these data into physical estimates of fluid presence, volume, and so forth; and (3) working toward constructing a fluid content model that is internally consistent and in sync with the other community modeling efforts.

Conclusions

CRESCENT was established to address pressing scientific and societal challenges related to subduction zone earthquake hazards, with an initial geographic and thematic focus on the CSZ. The center builds on decades of research, leverages a strong regional community of practice, and coordinates with complementary efforts locally and at other subduction zone systems (e.g., Southern California Earthquake Center, CoPES Hazards Research Hub, subduction zones in four dimensions), and also prioritizes the aggregation, standardization, and open dissemination of key observational and model products. These foundational datasets are intended to support both traditional analyses and emerging approaches, including machine learning and artificial intelligence (AI) and Bayesian frameworks that can, for example, interrogate paleoseismic records to evaluate alternative recurrence models and scenario ensembles, or lead to adoption of digital twins and use of generative AI techniques. Novel technologies, such as distributed acoustic sensing and satellite-based platforms like the NASA-ISRO SAR Mission, also promise to expand observational capabilities. Although the current scope is ambitious, it reflects only part of the long-term vision for CRESCENT. The center has a strong focus on community or consensus approaches upon which other transformational approaches can be developed. At the same time, other geohazards such as landslides, volcanoes, liquefaction, and wildfires remain important, yet lie outside the center's current activities. Over time, CRESCENT aims to broaden its reach and evolve into an integrated Earth systems center capable of addressing the full spectrum of cascading hazards in subduction zone environments. With its unique tectonic setting, densely populated basins, and rich scientific

infrastructure, the Pacific Northwest is ideally suited for such a holistic research enterprise. CRESCENT is building the scientific, computational, and collaborative foundation necessary for this evolution, with a focus on generating actionable knowledge for earthquake hazard mitigation in the present.

Data and Resources

All data sources are referenced. The Cascadia research-related proposals are available at <https://cascadiaquakes.org/science/#smallgrants>. The working groups have broad community buy-in at <https://cascadiaquakes.org>. There are no new data or resources to report for this article. Both the websites were last accessed in March 2026.

Declaration of Competing Interests

The authors acknowledge that there are no conflicts of interest recorded.

Acknowledgments

The authors thank Kelin Wang, Maureen Walton, and Belle Philibosian for detailed and constructive reviews, as well as Jeff Macguire and Robert McPherson for discussions. CRESCENT is funded by the National Science Foundation Cooperative Agreement Number 2225286. Additional funding is provided by the U.S. Geological Survey Cooperative Agreement Number G25AC00531 and Pacific Gas and Electric Company.

Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the views of CRESCENT, but do represent the views of the U.S. Geological Survey. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

- Abers, G. A. (2005). Seismic low-velocity layer at the top of subducting slabs: Observations, predictions, and systematics, *Phys. Earth Planet. In* **149**, nos. 1/2, 7–29.
- Aslam, K. S., A. M. Thomas, and D. Melgar (2021). The effect of fore-arc deformation on shallow earthquake rupture behavior in the Cascadia subduction zone, *Geophys. Res. Lett.* **48**, no. 20, e2021GL093941, doi: [10.1029/2021GL093941](https://doi.org/10.1029/2021GL093941).
- Atwater, B. F. (1987). Evidence for great Holocene earthquakes along the outer coast of Washington State, *Science* **236**, no. 4804, 942–944.
- Atwater, B. F., and E. Hemphill-Haley (1997). Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington, *U.S. Geol. Surv. Prof. Pap.* **1576**, 108 pp., doi: [10.3133/pp1576](https://doi.org/10.3133/pp1576).
- Atwater, B. F., A. R. Nelson, J. J. Clague, G. A. Carver, D. K. Yamaguchi, P. T. Bobrowsky, J. Bourgeois, M. E. Darienzo, W. C. Grant, E. Hemphill-Haley, et al. (1995). Summary of coastal geologic evidence for past great earthquakes at the Cascadia subduction zone, *Earthq. Spectra* **11**, 1–18.
- Audet, P., M. G. Bostock, N. I. Christensen, and S. M. Peacock (2009). Seismic evidence for over pressured subducted oceanic crust and megathrust fault sealing, *Nature* **457**, no. 7225, 7678.
- Barnett, E. A., R. A. Haugerud, B. L. Sherrod, C. S. Weaver, T. L. Pratt, and R. J. Blakely (2010). Preliminary atlas of active shallow tectonic deformation in the Puget Lowland, Washington, *U. S. Geol. Surv. Open-File Rept.* **2010-1149**.

- Bartlow, N. M. (2020). A long-term view of episodic tremor and slip in Cascadia, *Geophys. Res. Lett.* **47**, no. 3, e2019GL085303, doi: [10.1029/2019GL085303](https://doi.org/10.1029/2019GL085303).
- Becker, J. J., D. T. Sandwell, W. H. F. Smith, J. Braud, B. Binder, J. Depner, D. Fabre, J. Factor, S. Ingalls, S.-H. Kim, *et al.* (2009). Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS, *Mar. Geodes.* **32**, no. 4, 355–357, doi: [10.1080/01490410903297766](https://doi.org/10.1080/01490410903297766).
- Bedrosian, P. A., J. R. Peacock, E. Bowles-Martinez, A. Schultz, and G. J. Hill (2018). Crustal inheritance and a top-down control on arc magmatism at Mount St Helens, *Nature Geosci.* **11**, no. 11, 865–870.
- Belenky, M., H. Brown, G. Gangelhoff, and X. Liao (2014). *Own Your Risk Reframing Risk and Resiliency in the Columbia River Basin*, The Johns Hopkins University, School of Advanced International Studies & SwissRe, Baltimore, Maryland.
- Biasi, G. P., and S. G. Wesnousky (2016). Steps and gaps in ground ruptures: Empirical bounds on rupture propagation, *Bull. Seismol. Soc. Am.* **106**, no. 3, 1110–1124, doi: [10.1785/0120150175](https://doi.org/10.1785/0120150175).
- Black, B. A., J. K. Pearl, C. L. Pearson, P. T. Pringle, D. C. Frank, M. T. Page, B. M. Buckley, E. R. Cook, G. L. Harley, K. J. King, *et al.* (2023). A multifault earthquake threat for the Seattle metropolitan region revealed by mass tree mortality, *Sci. Adv.* **9**, no. 39, eadh4973, doi: [10.1126/sciadv.adh4973](https://doi.org/10.1126/sciadv.adh4973).
- Blettery, Q., A. M. Thomas, A. W. Rempel, and J. L. Hardebeck (2017). Imaging shear strength along subduction faults, *Geophys. Res. Lett.* **44**, no. 22, 311,329–311,339.
- Bodmer, M., D. R. Toomey, E. E. E. Hooft, and B. Schmandt (2018). Buoyant asthenosphere beneath Cascadia influences megathrust segmentation, *Geophys. Res. Lett.* **45**, no. 14, 6954–6962, doi: [10.1029/2018GL078700](https://doi.org/10.1029/2018GL078700).
- Boore, D. M., and W. B. Joyner (1997). Site amplification for generic rock sites, *Bull. Seismol. Soc. Am.* **87**, no. 2, 327–341.
- Booth-Rea, G., D. Klaeschen, I. Grevemeyer, and T. Reston (2008). Heterogeneous deformation in the Cascadia convergent margin and its relation to thermal gradient (Washington, NW USA), *Tectonics* **27**, no. 4, doi: [10.1029/2007TC002209](https://doi.org/10.1029/2007TC002209).
- Bosnic, I., P. J. Costa, F. Dourado, S. La Selle, and G. Gelfenbaum (2021). Onshore flow characteristics of the 1755 CE Lisbon tsunami: Linking forward and inverse numerical modeling, *Mar. Geol.* **434**, 106432.
- Bostock, M. G., N. I. Christensen, and S. M. Peacock (2019). Seismicity in Cascadia, *Lithos* **332**, 55–66.
- Brissaud, Q., C. D. Bowden, and V. Tsai (2020). Extension of the basin Rayleigh-wave amplification theory to include basin-edge effects, *Bull. Seismol. Soc. Am.* **110**, no. 3, 1305–1322.
- Bruzdzinski, M. R., and R. M. Allen (2007). Segmentation in episodic tremor and slip all along Cascadia, *Geology* **35**, no. 10, 907–910.
- Carbotte, S. M., B. Boston, S. Han, B. Shuck, J. Beeson, J. P. Canales, H. Tobin, N. Miller, M. Nedimovic, A. Tréhu, *et al.* (2024). Subducting plate structure and megathrust morphology from deep seismic imaging linked to earthquake rupture segmentation at Cascadia, *Sci. Adv.* **10**, no. 23, eadl3198, doi: [10.1126/sciadv.adl319](https://doi.org/10.1126/sciadv.adl319).
- Chang, S. E., and A. Falit-Baiamonte (2002). Disaster vulnerability of businesses in the 2001 Nisqually earthquake, *Global Environ. Change Part B* **4**, no. 2, 59–71.
- Chapman, J. S., and T. I. Melbourne (2009). Future Cascadia megathrust rupture delineated by episodic tremor and slip, *Geophys. Res. Lett.* **36**, no. 22, doi: [10.1029/2009GL040465](https://doi.org/10.1029/2009GL040465).
- Choi, Y., and J. P. Stewart (2005). Nonlinear site amplification as function of 30 m shear wave velocity, *Earthq. Spectra* **21**, 1–30.
- Clague, J. J. (1997). Evidence for large earthquakes at the Cascadia subduction zone, *Rev. Geophys.* **35**, no. 4, 439–460.
- Condit, C. B., M. E. French, J. A. Hayles, L. Y. Yeung, E. J. Chin, and C.-T. A. Lee (2022). Rheology of metasedimentary rocks at the base of the subduction seismogenic zone, *Geochem. Geophys. Geosyst.* **23**, no. 2, e2021GC010194, doi: [10.1029/2021GC010194](https://doi.org/10.1029/2021GC010194).
- Daniell, J. E., B. Khazai, F. Wenzel, and A. Vervaeck (2011). The CATDAT damaging earthquakes database, *Nat. Hazards Earth Syst. Sci.* **11**, no. 8, 2235–2251.
- Delano, J. E., C. B. Amos, J. P. Loveless, T. M. Rittenour, B. L. Sherrod, and E. M. Lynch (2017). Influence of the megathrust earthquake cycle on upper-plate deformation in the Cascadia forearc of Washington State, USA, *Geology* **45**, no. 11, 1051–1054.
- Delph, J. R., A. Levander, and F. Niu (2018). Fluid controls on the heterogeneous seismic characteristics of the Cascadia margin, *Geophys. Res. Lett.* **45**, 11,021–11,029, doi: [10.1029/2018GL079518](https://doi.org/10.1029/2018GL079518).
- Delph, J. R., A. M. Thomas, and A. Levander (2021). Subcretionary tectonics: Linking variability in the expression of subduction along the Cascadia forearc, *Earth Planet. Sci. Lett.* **556**, 116724.
- DeMets, C., R. G. Gordon, and D. F. Argus (2010). Geologically current plate motions, *Geophys. J. Int.* **181**, no. 1, 1–80.
- DeSanto, J. B., D. A. Schmidt, M. Zumberge, G. Sasagawa, and C. D. Chadwell (2025). Near full locking on the shallow megathrust of the central Cascadia subduction zone revealed by GNSS-Acoustic, *Earth Planet. Sci. Lett.* **665**, 119463, doi: [10.1016/j.epsl.2025.119463](https://doi.org/10.1016/j.epsl.2025.119463).
- Duckworth, W. C., C. B. Amos, E. R. Schermer, J. P. Loveless, and T. M. Rittenour (2021). Slip and strain accumulation along the Sadie Creek fault, Olympic Peninsula, Washington, *J. Geophys. Res. Solid Earth* **126**, no. 3, 2020JB020276, doi: [10.1029/2020JB020276](https://doi.org/10.1029/2020JB020276).
- Egbert, G. D., B. Yang, P. A. Bedrosian, K. Key, D. W. Livelybrooks, A. Schultz, A. Kelbert, and B. Parris (2022). Fluid transport and storage in the Cascadia forearc influenced by overriding plate lithology, *Nature Geosci.* **15**, 677–682, doi: [10.1038/s41561-022-00981-8](https://doi.org/10.1038/s41561-022-00981-8).
- Erickson, B. A., J. Jiang, M. Barall, N. Lapusta, E. M. Dunham, R. Harris, L. S. Abrahams, K. L. Allison, J. P. Ampuero, S. Barbot, *et al.* (2020). The community code verification exercise for simulating sequences of earthquakes and aseismic slip (SEAS), *Seismol. Res. Lett.* **91**, no. 2A, 874–890, doi: [10.1785/0220190248](https://doi.org/10.1785/0220190248).
- Field, E. H., G. P. Biasi, P. Bird, T. E. Dawson, K. R. Felzer, D. D. Jackson, K. M. Johnson, T. H. Jordan, C. Madden, A. J. Michael, *et al.* (2015). Long-term time-dependent probabilities for the third Uniform California Earthquake Rupture Forecast (UCERF3), *Bull. Seismol. Soc. Am.* **105**, no. 2A, 511–543.
- Frankel, A., and A. Grant (2021). Site response, basin amplification, and earthquake stress drops in the Portland, Oregon area, *Bull. Seismol. Soc. Am.* **111**, no. 2, 671–685, doi: [10.1785/0120020269](https://doi.org/10.1785/0120020269).
- Frankel, A., R. Chen, M. Petersen, M. Moschetti, and B. Sherrod (2015). 2014 Update of the Pacific Northwest portion of the U.S. National Seismic Hazard Maps, *Earthq. Spectra* **31**, no. 1_suppl, S131–S148, doi: [10.1193/111314EQS193M](https://doi.org/10.1193/111314EQS193M).
- Furumura, T. (2005). Subduction zone guided waves and the heterogeneity structure of the subducted plate: Intensity anomalies in

- northern Japan, *J. Geophys. Res.* **110**, no. B10, doi: [10.1029/2004JB003486](https://doi.org/10.1029/2004JB003486).
- Gallovič, F., L. Valentová, J.-P. Ampuero, and A.-A. Gabriel (2019). Bayesian dynamic finite-fault inversion: 1. Method and synthetic test, *J. Geophys. Res. Solid Earth* **124**, no. 7, 6949–6969.
- Gao, X., and K. Wang (2017). Rheological separation of the megathrust seismogenic zone and episodic tremor and slip, *Nature* **543**, no. 7645, 416–419.
- Goldfinger, C., J. Beeson, B. Black, A. Vizcaino, C. H. Nelson, A. Morey, J. R. Patton, J. Gutiérrez-Pastor, C. Romsos, and M. D. Walczak (2025). Unravelling the dance of earthquakes: Evidence of partial synchronization of the northern San Andreas fault and Cascadia megathrust, *Geosphere* **21**, 1132–1180.
- Goldfinger, C., S. Galer, J. Beeson, T. Hamilton, B. Black, C. Romsos, J. Patton, C. H. Nelson, R. Hausmann, and A. Morey (2017). The importance of site selection, sediment supply, and hydrodynamics: A case study of submarine paleoseismology on the northern Cascadia margin, Washington USA, *Mar. Geol.* **384**, 4–46.
- Goldfinger, C., K. Grijalva, R. Bürgmann, A. E. Morey, J. E. Johnson, C. H. Nelson, J. Gutiérrez-Pastor, A. Ericsson, E. Karabanov, J. D. Chaytor, *et al.* (2008). Late Holocene rupture of the northern San Andreas fault and possible stress linkage to the Cascadia subduction zone, *Bull. Seismol. Soc. Am.* **98**, no. 2, 861–889.
- Goldfinger, C., C. H. Nelson, A. E. Morey, J. E. Johnson, J. R. Patton, E. Karabanov, J. Gutiérrez-Pastor, A. T. Eriksson, E. Gràcia, G. Dunhill, *et al.* (2012). Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone, *U.S. Geol. Surv. Profess. Pap.* 1661–F, 170 pp.
- González, F. I., K. Satake, E. F. Boss, and H. O. Mofjeld (1995). Edge wave and non-trapped modes of the 25 April 1992 Cape Mendocino tsunami, *Pure Appl. Geophys.* **144**, no. 3, 409–426.
- Guo, H., J. J. McGuire, and H. Zhang (2021). Correlation of porosity variations and rheological transitions on the southern Cascadia megathrust, *Nature Geosci.* **14**, no. 5, 341–348.
- Hamling, I. J., S. Hreinsdóttir, K. Clark, J. Elliott, C. Liang, E. Fielding, N. Litchfield, P. Villamor, L. Wallace, and T. J. Wright (2017). Complex multifault rupture during the 2016 M_w 7.8 Kaikōura earthquake, New Zealand, *Science* **356**, no. 6334, doi: [10.1126/science.aam7194](https://doi.org/10.1126/science.aam7194).
- Han, S., N. L. Bangs, S. M. Carbotte, D. M. Saffer, and J. C. Gibson (2017). Links between sediment consolidation and Cascadia megathrust slip behavior, *Nature Geosci.* **10**, no. 12, 954–959.
- Harris, R. A., M. Barall, B. Aagaard, S. Ma, D. Roten, K. Olsen, B. Duan, D. Liu, B. Luo, K. Bai, *et al.* (2018). A suite of exercises for verifying dynamic earthquake rupture codes, *Seismol. Res. Lett.* **89**, no. 3, 1146–1162.
- Hayes, G. P., G. L. Moore, D. E. Portner, M. Hearne, H. Flamme, M. Furtney, and G. M. Smoczyk (2018). Slab2, a comprehensive subduction zone geometry model, *Science* **362**, no. 6410, 58–61.
- Hellweg, M., D. S. Dreger, A. Lomax, R. C. McPherson, and L. Dengler (2024). The 2021 and 2022 North Coast California earthquake sequences and fault complexity in the vicinity of the Mendocino Triple Junction, *Bull. Seismol. Soc. Am.* **115**, no. 1, 140–162.
- Hirahara, K., and K. Nishikiori (2019). Estimation of frictional properties and slip evolution on a long-term slow slip event fault with the ensemble Kalman filter: Numerical experiments, *Geophys. J. Int.* **219**, no. 3, 2074–2096.
- Horst, A. E., A. R. Streig, R. E. Wells, and J. Bershaw (2021). Multiple Holocene earthquakes on the Gales Creek fault, northwest Oregon fore-arc, *Bull. Seismol. Soc. Am.* **111**, no. 1, 476–489.
- Horton, B. P., R. J. Edwards, and J. M. Lloyd (2000). Implications of a microfossil-based transfer function in Holocene sea-level studies, in *Holocene Land–Ocean Interaction and Environmental Change Around the North Sea*, I. Shennan and J. Andrews (Editors), The Geological Society, London, United Kingdom, doi: [10.1144/GSL.SP.2000.166.01.03](https://doi.org/10.1144/GSL.SP.2000.166.01.03).
- Houston, H., B. G. Delbridge, A. G. Wech, and K. C. Creager (2011). Rapid tremor reversals in Cascadia generated by a weakened plate interface, *Nature Geosci.* **4**, no. 6, 404–409.
- Hutchinson, I., and J. Clague (2017). Were they all giants? Perspectives on late Holocene plate-boundary earthquakes at the northern end of the Cascadia subduction zone, *Quat. Sci. Rev.* **169**, 29–49.
- Hyndman, R. D., M. Yamano, and D. A. Oleskevich (1997). The seismogenic zone of subduction thrust faults, *Isl. Arc* **6**, 244–260, doi: [10.1111/j.1440-1738.1997.tb00175.x](https://doi.org/10.1111/j.1440-1738.1997.tb00175.x).
- Ichinose, G. A., H. K. Thio, and P. G. Somerville (2004). Rupture process and near-source shaking of the 1965 Seattle-Tacoma and 2001 Nisqually, intraslab earthquakes, *Geophys. Res. Lett.* **31**, no. 10, doi: [10.1029/2004GL019668](https://doi.org/10.1029/2004GL019668).
- Ide, S., and G. C. Beroza (2023). Slow earthquake scaling reconsidered as a boundary between distinct modes of rupture propagation, *Proc. Natl. Acad. Sci. Unit. States Am.* **120**, no. 32, e2222102120, doi: [10.1073/pnas.2222102120](https://doi.org/10.1073/pnas.2222102120).
- Kemp, A. C., N. Cahill, S. E. Engelhart, A. D. Hawkes, and K. Wang (2018). Revising estimates of spatially variable subsidence during the AD 1700 Cascadia earthquake using a Bayesian foraminiferal transfer function, *Bull. Seismol. Soc. Am.* **108**, no. 2, 654–673.
- Kolaj, M., S. C. Halchuk, and J. Adams (2023). Sixth-generation seismic hazard model of Canada: Grid values of mean hazard to be used with the 2020 National Building Code of Canada, version 1.0, *Geol. Surv. Canada Open-File Rept.* 8950, 14 pp., doi: [10.4095/331497](https://doi.org/10.4095/331497).
- Kong, Q., D. T. Trugman, Z. E. Ross, M. J. Bianco, B. J. Meade, and P. Gerstoft (2019). Machine learning in seismology: Turning data into insights, *Seismol. Res. Lett.* **90**, no. 1, 3–14.
- Krenz, L., C. Uphoff, T. Ulrich, A. A. Gabriel, L. S. Abrahams, E. M. Dunham, and M. Bader (2021). 3D acoustic-elastic coupling with gravity: the dynamics of the 2018 Palu, Sulawesi earthquake and tsunami, *Proc. of the International Conf. for High Performance Computing, Networking, Storage and Analysis*, 1–14.
- La Selle, S. M., A. R. Nelson, R. C. Witter, B. E. Jaffe, G. Gelfenbaum, and J. S. Padgett (2024). Testing megathrust rupture models using tsunami deposits, *J. Geophys. Res.* **129**, no. 5, e2023JF007444, doi: [10.1029/2023JF007444](https://doi.org/10.1029/2023JF007444).
- Lebakula, V., J. Epting, J. Moehl, C. Stipek, D. Adams, A. Reith, J. Kaufman, J. Gonzales, B. Reynolds, S. Basford, *et al.* (2024). LandScan Silver Edition [Data set], Oak Ridge National Laboratory, doi: [10.48690/1531770](https://doi.org/10.48690/1531770).
- Li, D., and Y. Liu (2021). Cascadia megathrust earthquake rupture model constrained by geodetic fault locking, *Philos. Trans. Roy. Soc. Lond. A* **379**, no. 2196, 20200135.
- Li, S., K. Wang, Y. Wang, Y. Jiang, and S. E. Dosso (2018). Geodetically inferred locking state of the Cascadia megathrust based on a visco-elastic Earth model, *J. Geophys. Res. Solid Earth* **123**, no. 9, 8056–8072.

- Littel, G., M. Bostock, C. Sammis, S. Peacock, and A. Calvert (2023). Tectonic tremor: The chatter of mafic underplating, *Seismica* **2**, no. 4, doi: [10.26443/seismica.v2i4.1599](https://doi.org/10.26443/seismica.v2i4.1599).
- Lucas, M., H. Tobin, S. Carbotte, S. Han, B. Boston and , and CASIE21 Scientific Team (2021). Investigating potential dynamic backstop splay faulting in the Cascadia accretionary wedge using new seismic reflection images from the Cascadia seismic imaging experiment 2021, *AGU Fall Meeting*, T15D0193.
- Mann, M. E., and G. A. Abers (2020). First-order mantle subduction-zone structure effects on ground motion: The 2016 M_w 7.1 Iniskin and 2018 M_w 7.1 Anchorage earthquakes, *Seismol. Res. Lett.* **91**, no. 1, 85–93, doi: [10.1785/0220190197](https://doi.org/10.1785/0220190197).
- McCrory, P. A., J. L. Blair, F. Waldhauser, and D. H. Oppenheimer (2012). Juan de Fuca slab geometry and its relation to Wadati-Benioff zone seismicity, *J. Geophys. Res. Solid Earth* **117**, no. B9, B09306.
- McGary, R. S., R. L. Evans, P. E. Wannamaker, J. Elsenbeck, and S. Rondenay (2014). Pathway from subducting slab to surface for melt and fluids beneath Mount Rainier, *Nature* **511**, no. 7509, 338–340, doi: [10.1038/nature13493](https://doi.org/10.1038/nature13493).
- Melgar, D. (2021). Was the January 26th, 1700 Cascadia earthquake part of a rupture sequence? *J. Geophys. Res. Solid Earth* **126**, no. 10, e2021JB021822, doi: [10.1029/2021JB021822](https://doi.org/10.1029/2021JB021822).
- Melgar, D., V. J. Sahakian, and A. M. Thomas (2022). Deep coseismic slip in the Cascadia megathrust can be consistent with coastal subsidence, *Geophys. Res. Lett.* **49**, no. 3, e2021GL097404, doi: [10.1029/2021GL097404](https://doi.org/10.1029/2021GL097404).
- Milker, Y., A. R. Nelson, B. P. Horton, S. E. Engelhart, L.-A. Bradley, and R. C. Witter, 2016, Differences in coastal subsidence in southern Oregon (USA) during at least six prehistoric megathrust earthquakes, *Quat. Sci. Rev.* **142**, 143–163.
- Morell, K. D., R. Styron, M. Stirling, J. Griffin, R. Archuleta, and T. Onur (2020). Seismic hazard analyses from geologic and geomorphic data: Current and future challenges, *Tectonics* **39**, e2018TC005365, doi: [10.1029/2018TC005365](https://doi.org/10.1029/2018TC005365).
- Murray, M. H., G. A. Marshall, M. Lisowski, and R. S. Stein (1996). The 1992 $M = 7$ Cape Mendocino, California, earthquake: Coseismic deformation at the south end of the Cascadia megathrust, *J. Geophys. Res. Solid Earth* **101**, no. B8, 17,707–17,725.
- Nelson, A. R. (1992). Discordant 14C ages from buried tidal-marsh soils in the Cascadia subduction zone, southern Oregon coast, *Quat. Res.* **38**, no. 1, 74–90, doi: [10.1016/0033-5894\(92\)90031-D](https://doi.org/10.1016/0033-5894(92)90031-D).
- Nelson, A. R., C. B. DuRoss, R. C. Witter, H. M. Kelsey, S. E. Engelhart, S. A. Mahan, H. J. Gray, A. D. Hawkes, B. P. Horton, and J. S. Padgett (2021). A maximum rupture model for the central and southern Cascadia subduction zone—Reassessing ages for coastal evidence of megathrust earthquakes and tsunamis, *Quat. Sci. Rev.* **261**, 106922.
- Nelson, A. R., H. M. Kelsey, and R. C. Witter (2006). Great earthquakes of variable magnitude at the Cascadia subduction zone, *Quat. Res.* **65**, no. 3, 354–365.
- Nelson, A. R., S. F. Personius, B. L. Sherrod, H. M. Kelsey, S. Y. Johnson, L.-A. Bradley, and R. E. Wells (2014). Diverse rupture modes for surface-deforming upper plate earthquakes in the southern Puget Lowland of Washington State, *Geosphere* **10**, no. 4, 769–796.
- Nelson, A. R., E. Shennan, and A. J. Long (1996). Identifying coseismic subsidence in tidal wetland stratigraphic sequences at the Cascadia subduction zone of western North America, *J. Geophys. Res.* **101**, 6115–6135.
- Nieminski, N. M., Z. Sylvester, J. A. Covault, J. Gombert, L. Staisch, and I. W. McBrearty (2025). Turbidite correlation for paleoseismology, *Geol. Soc. Am. Bull.* **137**, nos. 1/2, 29–40, doi: [10.1130/B37343.1](https://doi.org/10.1130/B37343.1).
- Nocquet, J. M., P. Jarrin, M. Vallée, P. A. Mothes, R. Grandin, F. Rolandone, B. Delouis, H. Yepes, Y. Font, D. Fuentes, *et al.* (2017). Supercycle at the Ecuadorian subduction zone revealed after the 2016 Pedernales earthquake, *Nature Geosci.* **10**, no. 2, 145–149.
- Nguyen, C. P., and D. A. Schmidt (2021). Filling the gap in Cascadia: The emergence of low-amplitude long-term slow slip, *Geochem. Geophys. Geosys.* **22**, no. 3, e2020GC009477, doi: [10.1029/2020GC009477](https://doi.org/10.1029/2020GC009477).
- Obara, K. (2002). Nonvolcanic deep tremor associated with subduction in southwest Japan, *Science* **296**, no. 5573, 1679–1681.
- Oglesby, D. D., and R. J. Archuleta (1997). A faulting model for the 1992 Petrolia earthquake: Can extreme ground acceleration be a source effect?, *J. Geophys. Res. Solid Earth* **102**, no. B6, 11877–11897.
- Olsen, K. B., W. J. Stephenson, and A. Geisselmeyer (2008). 3D crustal structure and long-period ground motions from a M 9.0 megathrust earthquake in the Pacific Northwest region, *J. Seismol.* **12**, no. 2, 145–159.
- Oppenheimer, D., J. Eaton, A. Jayko, M. Lisowski, G. Marshall, M. Murray, R. Simpson, R. Stein, G. Beroza, and M. Magee (1993). The Cape Mendocino, California, earthquakes of April 1992: Subduction at the triple junction, *Science* **261**, no. 5120, 433–438.
- Oregon Department of Geology and Mineral Industries (2013). Tsunami evacuation map Seaside & Gearhart, Oregon, Oregon Department of Geology and Mineral Industries, available at <https://www.oregon.gov/dogami/tsuclearinghouse/Pages/default.aspx> (last accessed March 2026).
- Oregon Seismic Safety Policy Advisory Commission (OSSPAC) (2013). The Oregon resilience plan reducing risk and improving recovery for the next Cascadia earthquake and Tsunami, *A Report to 77th Legislative Assembly*, available at https://www.oregon.gov/oem/documents/oregon_resilience_plan_final.pdf (last accessed September 2024).
- Padgett, J. S., S. E. Engelhart, H. M. Kelsey, R. C. Witter, N. Cahill, and E. Hemphill-Haley (2021). Timing and amount of southern Cascadia earthquake subsidence over the past 1700 years at northern Humboldt Bay, California, USA, *GSA Bull.* **133**, nos. 9/10, 2137–2156, doi: [10.1130/b35701.1](https://doi.org/10.1130/b35701.1).
- Personius, S. F., R. W. Briggs, A. R. Nelson, E. R. Schermer, J. Z. Maharrey, B. L. Sherrod, S. A. Spaulding, and L.-A. Bradley (2014). Holocene earthquakes and right-lateral slip on the left-lateral Darrington–Devils Mountain fault zone, northern Puget Sound, Washington, *Geosphere* **10**, no. 6, 1482–1500.
- Petersen, M. D., A. M. Shumway, P. M. Powers, C. S. Mueller, M. P. Moschetti, A. D. Frankel, S. Rezaeian, D. E. McNamara, N. Luco, O. S. Boyd, *et al.* (2020). The 2018 update of the US National Seismic Hazard Model: Overview of model and implications, *Earthq. Spectra* **36**, no. 1, 5–41.
- Petersen, M. D., A. M. Shumway, P. M. Powers, E. H. Field, M. P. Moschetti, K. S. Jaiswal, K. R. Milner, S. Rezaeian, A. D. Frankel, A. L. Llenos, *et al.* (2024). The 2023 US 50-state national seismic hazard model: Overview and implications, *Earthq. Spectra* **40**, no. 1, 5–88.

- Pizer, C., K. Clark, J. Howarth, A. Howell, J. Delano, B. W. Hayward, and N. Litchfield (2024). A 5000 yr record of coastal uplift and subsidence reveals multiple source faults for past earthquakes on the central Hikurangi margin, New Zealand, *Geol. Soc. Am. Bull.* **136**, nos. 7/8, 2702–2722, doi: [10.1130/G52797.1](https://doi.org/10.1130/G52797.1).
- Priest, G. R., C. Goldfinger, K. Wang, R. C. Witter, Y. Zhang, and A. M. Baptista (2010). Confidence levels for tsunami-inundation limits in northern Oregon inferred from a 10,000-year history of great earthquakes at the Cascadia subduction zone, *Nat. Hazards* **54**, no. 1, 27–73.
- Raghunandan, M., A. B. Liel, and N. Luco (2015). Collapse risk of buildings in the Pacific northwest region due to subduction earthquakes, *Earthq. Spectra* **31**, no. 4, 2087–2115.
- Ramos, M. D., Y. Huang, T. Ulrich, D. Li, A. A. Gabriel, and A. M. Thomas (2021). Assessing margin wide rupture behaviors along the Cascadia megathrust with 3-D dynamic rupture simulations, *J. Geophys. Res. Solid Earth* **126**, no. 7, e2021JB022005, doi: [10.1029/2021JB022005](https://doi.org/10.1029/2021JB022005).
- Rekoske, J. M., M. P. Moschetti, and E. M. Thompson (2022). Basin and site effects in the US Pacific Northwest estimated from small-magnitude earthquakes, *Bull. Seismol. Soc. Am.* **112**, no. 1, 438–456.
- Richter, T., C. Sens-Schönfelder, R. Kind, and G. Asch (2014). Comprehensive observation and modeling of earthquake and temperature-related seismic velocity changes in northern Chile with passive image interferometry, *J. Geophys. Res. Solid Earth* **119**, no. 6, 4747–4765.
- Rogers, G., and H. Dragert (2003). Episodic tremor and slip on the Cascadia subduction zone: The chatter of silent slip, *Science* **300**, no. 5627, 1942–1943.
- Rosenau, M., J. Lohrmann, and O. Oncken (2009). Shocks in a box: An analogue model of subduction earthquake cycles with application to seismotectonic forearc evolution, *J. Geophys. Res.* **114**, no. B14, doi: [10.1029/2008JB005665](https://doi.org/10.1029/2008JB005665).
- Roten, D., K. B. Olsen, and R. Takedatsu (2020). Numerical simulation of M9 megathrust earthquakes in the Cascadia subduction zone, *Pure Appl. Geophys.* **177**, no. 5, 2125–2141, doi: [10.1007/s00024-018-2085-5](https://doi.org/10.1007/s00024-018-2085-5).
- Royer, A. A., A. M. Thomas, and M. G. Bostock (2015). Tidal modulation and triggering of low-frequency earthquakes in northern Cascadia, *J. Geophys. Res. Solid Earth* **120**, no. 1, 384–405.
- Rubinstein, J. L., J. E. Vidale, J. Gomberg, P. Bodin, K. C. Creager, and S. D. Malone (2007). Nonvolcanic tremor driven by large transient shear stresses, *Nature* **448**, no. 7153, 579–582.
- Sahakian, V. J., D. Melgar, L. Quintanar, L. Ramírez-Guzmán, X. Pérez-Campos, and A. Baltay (2018). Ground motions from the 7 and 19 September 2017 Tehuantepec and Puebla-Morelos, Mexico, earthquakes, *Bull. Seismol. Soc. Am.*, doi: [10.1785/0120180108](https://doi.org/10.1785/0120180108).
- Sahakian, V. J., A. J. Meigs, A. Clifford, S. Fasola, D. Melgar, A. M. Thomas, P.-E. Share, H. Tobin, T. Melbourne, J. Elizabeth, et al. (2026). The Cascadia Region Earthquake Science Center (CRESCENT): Regional science in a resilience context, *Seismol. Res. Lett.*, doi: [10.1785/0220250423](https://doi.org/10.1785/0220250423).
- Satake, K., K. Shimazaki, Y. Tsuji, and K. Ueda (1996). Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700, *Nature* **379**, no. 6562, 246–249.
- Schermer, E. R., C. B. Amos, W. C. Duckworth, A. R. Nelson, S. Angster, J. Delano, and B. L. Sherrod (2020). Postglacial M_w 7.0–7.5 Earthquakes on the North Olympic fault zone, Washington, *Bull. Seismol. Soc. Am.* **111**, no. 1, 490–513.
- Schmalzle, G. M., R. McCaffrey, and K. C. Creager (2014). Central Cascadia subduction zone creep, *Geochim. Geophys. Geosys.* **15**, no. 4, 1515–1532.
- Sherrod, B., and J. Gomberg (2014). Crustal earthquake triggering by pre-historic great earthquakes on subduction zone thrusts, *J. Geophys. Res. Solid Earth* **119**, no. 2, 1273–1294.
- Silva, W. J., I. G. Wong, and R. B. Darragh (1998). Engineering characterizations of earthquake strong ground motions in the Pacific Northwest, in *Assessing Earthquake Hazards and Reducing Risk in the Pacific Northwest*, A. M. Rogers, T. J. Walsh, W. J. Kockelman, and G. R. Preist (Editors), U.S. Geological Survey, Denver, Colorado, 313–324.
- Small, D., D. Melgar, S. La Selle, and A. Meigs (2025). Combining multisite Tsunami and deformation modeling to constrain slip distributions for the 1700 CE Cascadia earthquake, *Bull. Seismol. Soc. Am.* **115**, no. 2, 431–451, doi: [10.1785/0120240218](https://doi.org/10.1785/0120240218).
- Spica, Z. J., K. Nishida, T. Akuhara, F. Pétrélis, M. Shinohara, and T. Yamada (2020). Marine sediment characterized by ocean-bottom fiber-optic seismology, *Geophys. Res. Lett.* **47**, no. 16, e2020GL088360, doi: [10.1029/2020GL088360](https://doi.org/10.1029/2020GL088360).
- St. Clair, J., S. Moon, W. S. Holbrook, J. T. Perron, C. S. Riebe, S. J. Martel, B. Carr, C. Harman, K. Singha, and D. Richter (2015). Geophysical imaging reveals topographic stress control of bedrock weathering, *Science* **350**, no. 6260, 534–538, doi: [10.1126/science.aab2210](https://doi.org/10.1126/science.aab2210).
- Staisch, L. (2024). Sensitivity testing of marine turbidite age estimates along the Cascadia subduction zone, *Bull. Seismol. Soc. Am.* **114**, no. 3, 1739–1753, doi: [10.1785/0120230252](https://doi.org/10.1785/0120230252).
- Staisch, L. M., and M. A. Walton (2022). Cascadia subduction zone database: Compilation of published datasets relevant to Cascadia subduction zone earthquake hazards and tectonics (2022), U.S. Geological Survey Data Release, doi: [10.5066/P9O69X6E](https://doi.org/10.5066/P9O69X6E).
- Stein, R. S., A. A. Barka, and J. H. Dieterich (1997). Progressive failure on the North Anatolian fault since 1939 by earthquake stress triggering, *Geophys. J. Int.* **128**, no. 3, 594–604.
- Stephenson, W. J., N. G. Reitman, and S. J. Angster (2017). P- and S-wave velocity models incorporating the Cascadia subduction zone for 3D earthquake ground motion simulations, Version 1.6—Update for Open-File Report 2007–1348, *Open-File Report 2017–1152*, Version 1.1: September 11, 2019; Version 1.0: December 20, 2017, doi: [10.3133/ofr20171152](https://doi.org/10.3133/ofr20171152).
- Stone, I., J. E. Vidale, S. Han, and E. Roland (2018). Catalog of offshore seismicity in Cascadia: Insights into the regional distribution of microseismicity and its relation to subduction processes, *J. Geophys. Res.* **123**, no. 1, 641–652, doi: [10.1002/2017JB014966](https://doi.org/10.1002/2017JB014966).
- TenCate, J. A., D. Pasqualini, S. Habib, K. Heitmann, D. Higdon, and P. A. Johnson (2004). Nonlinear and nonequilibrium dynamics in geomaterials, *Phys. Rev. Lett.* **93**, no. 6, 65501.
- Thompson, M., E. A. Wirth, A. D. Frankel, J. Renate Hartog, and J. E. Vidale (2020). Basin amplification effects in the Puget Lowland, Washington, from strong-motion recordings and 3D simulations, *Bull. Seismol. Soc. Am.* **110**, no. 2, 534–555.
- Thrush, C., and R. S. Ludwin (2007). Finding fault: Indigenous seismology, colonial science, and the rediscovery of earthquakes and tsunamis in Cascadia, *Am. Indian Culture Res. J.* **31**, no. 4, 1–24.

- Toomey, D. R., R. M. Allen, A. H. Barclay, S. W. Bell, P. D. Bromirski, R. L. Carlson, X. Chen, J. A. Collins, R. P. Dziak, B. Evers, *et al.* (2014). A sea change in seismological studies of subduction zones, *Oceanography* **27**, no. 2, 138–150.
- Tréhu, A. M., R. J. Blakely, and M. C. Williams (2012). Subducted seamounts and recent earthquakes beneath the central Cascadia forearc, *Geology* **40**, no. 2, 103–106.
- Tréhu, A. M., J. Braunmiller, and E. Davis (2015). Seismicity of the Central Cascadia Continental margin near 44.5° N: A decadal view, *Seismol. Res. Lett.* **86**, no. 3, 819–829.
- U.S. Geological Survey (2020). Quaternary fault and fold database for the Nation, doi: [10.5066/P9BCVRCCK](https://doi.org/10.5066/P9BCVRCCK).
- Ulrich, T., A. A. Gabriel, and E. H. Madden (2022). Stress, rigidity and sediment strength control megathrust earthquake and tsunami dynamics, *Nature Geosci.* 1–7, doi: [10.1038/s41561-021-00863-5](https://doi.org/10.1038/s41561-021-00863-5).
- Unjoh, S., M. Kaneko, S. Kataoka, K. Nagaya, and K. Matsuoka (2012). Effect of earthquake ground motions on soil liquefaction, *Soils Found.* **52**, no. 5, 830–841, doi: [10.1016/j.sandf.2012.11.006](https://doi.org/10.1016/j.sandf.2012.11.006).
- Viens, L., M. A. Denolle, N. Hirata, and S. Nakagawa (2018). Complex near-surface rheology inferred from the response of greater Tokyo to strong ground motions, *J. Geophys. Res. Solid Earth* **123**, no. 7, 5710–5729.
- Walton, M. A. L., L. M. Staisch, T. Dura, J. K. Pearl, B. Sherrod, J. Gombert, S. Engelhart, A. Tréhu, J. Watt, J. Perkins, *et al.* (2021). Toward an integrative geological and geophysical view of Cascadia subduction zone earthquakes, *Annu. Rev. Earth Planet. Sci.* **49**, no. 1, 367–398.
- Wang, K. (2024). Thermal control on the updip and downdip extents of megathrust earthquake rupture: Revisiting Dr. Roy Hyndman's seminal contributions 30 years later, *Can. J. Earth Sci.* **62**, no. 4, 710–724.
- Wang, K., and A. M. Tréhu (2016). Invited review paper: Some outstanding issues in the study of great megathrust earthquakes—The Cascadia example, *J. Geodynam.* **98**, 1–18.
- Wang, K., R. Wells, S. Mazzotti, R. D. Hyndman, and T. Sagiya (2003). A revised dislocation model of interseismic deformation of the Cascadia subduction zone, *J. Geophys. Res. Solid Earth* **108**, no. B1, doi: [10.1029/2001JB001227](https://doi.org/10.1029/2001JB001227).
- Wang, P. L., S. E. Engelhart, K. Wang, A. D. Hawkes, B. P. Horton, A. R. Nelson, and R. C. Witter (2013). Heterogeneous rupture in the great Cascadia earthquake of 1700 inferred from coastal subsidence estimates, *J. Geophys. Res. Solid Earth* **118**, no. 5, 2460–2473.
- Wang, Y., F. C. Lin, and K. M. Ward (2019). Ambient noise tomography across the Cascadia subduction zone using dense linear seismic arrays and double beamforming, *Geophys. J. Int.* **217**, no. 3, 1668–1680.
- Watt, J. T., and D. S. Brothers (2021). Systematic characterization of morphotectonic variability along the Cascadia convergent margin: Implications for shallow megathrust behavior and tsunami hazards, *Geosphere* **17**, no. 1, 95–117.
- Weber, E., J. Moehl, S. Weston, A. Rose, C. Brelsford, and T. Hauser (2022). LandScan USA 2021 [Data set], Oak Ridge National Laboratory, doi: [10.48690/1527701](https://doi.org/10.48690/1527701).
- Wells, R. E., R. J. Blakely, Y. Sugiyama, D. W. Scholl, and P. A. Dinterman (2003). Basin-centered asperities in great subduction zone earthquakes: A link between slip, subsidence, and subduction erosion? *J. Geophys. Res. Solid Earth* **108**, no. B10, doi: [10.1029/2002JB002072](https://doi.org/10.1029/2002JB002072).
- Wells, R. E., R. J. Blakely, A. G. Wech, P. A. McCrory, and A. Michael (2017). Cascadia subduction tremor muted by crustal faults, *Geology* **45**, no. 6, 515–518.
- Wells, R. E., D. Burky, R. Friedman, D. Pyle, R. Duncan, P. Haeussler, and J. Wooden (2014). Siletzia, a large igneous province in the Oregon and Washington Coast Range: Correlation with the geomagnetic polarity timescale and implications for a long-lived Yellowstone hot spot, *Geosphere* **10**, no. 4, 1–28.
- Wells, D. L., and K. J. Coppersmith (1994). New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, *Bull. Seismol. Soc. Am.* **84**, no. 4, 974–1002.
- West, M. E., A. Bender, M. Gardine, L. Gardine, K. Gately, P. Haeussler, W. Hassan, F. Meyer, C. Richards, N. Ruppert, *et al.* (2020). The 30 November 2018 M_w 7.1 Anchorage earthquake, *Seismol. Res. Lett.* **91**, no. 1, 66–84.
- Wilkinson, M. D., M. Dumontier, I. J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J. W. Boiten, L. B. da Silva Santos, P. E. Bourne, *et al.* (2016). The FAIR Guiding Principles for scientific data management and stewardship, *Sci. Data* **3**, no. 1, 160018, doi: [10.1038/sdata.2016.18](https://doi.org/10.1038/sdata.2016.18).
- Wirth, E. A., and A. D. Frankel (2019). Impact of down-dip rupture limit and high-stress drop subevents on coseismic land-level change during Cascadia megathrust earthquakes, *Bull. Seismol. Soc. Am.* **109**, no. 6, 2187–2197, doi: [10.1785/0120190043](https://doi.org/10.1785/0120190043).
- Wirth, E. A., V. J. Sahakian, L. M. Wallace, and D. Melnick (2022). The occurrence and hazards of great subduction zone earthquakes, *Nat. Rev. Earth Environ.* **3**, no. 2, 125–140.
- Witter, R. C., H. M. Kelsey, and E. Hemphill-Haley (2003). Great Cascadia earthquakes and tsunamis of the past 6,700 years, Coquille River estuary, southern coastal Oregon, *Geol. Soc. Am. Bull.* **115**, no. 10, 1289–1306.
- Witter, R. C., Y. Zhang, K. Wang, G. R. Priest, C. Goldfinger, L. L. Stimely, J. T. English, and P. A. Ferro (2011). Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios, *Oregon Department of Geology and Mineral Industries Special Paper*, 43, 57 pp.
- Witter, R. C., Y. J. Zhang, K. Wang, G. R. Priest, C. Goldfinger, L. Stimely, J. T. English, and P. A. Ferro (2013). Simulated tsunami inundation for a range of Cascadia megathrust earthquake scenarios at Bandon, Oregon, USA, *Geosphere*, doi: [10.1130/GES00899.1](https://doi.org/10.1130/GES00899.1).
- Wong, F. L., and M. S. Grim (2015). Depth-to-basement, sediment-thickness, and bathymetry data for the deep-sea basins offshore of Washington, Oregon, and California, *U.S. Geol. Surv. Open-File Rept. No.* 2015-1118.
- Wood, N., J. Jones, M. Schmidlein, J. Schelling, and T. Frazier (2016). Pedestrian flow-path modeling to support tsunami evacuation and disaster relief planning in the US Pacific Northwest, *Int. J. Disaster Risk Reduct.* **18**, 41–55, doi: [10.1016/j.ijdrr.2016.05.010](https://doi.org/10.1016/j.ijdrr.2016.05.010).
- Wood, N. J., J. Jones, S. Spielman, and M. C. Schmidlein (2015). Community clusters of tsunami vulnerability in the US Pacific Northwest, *Proc. Natl. Acad. Sci. Unit. States Am.* **112**, no. 17, 5354–5359, doi: [10.1073/pnas.1420309112](https://doi.org/10.1073/pnas.1420309112).
- Yamaguchi, D. K., B. F. Atwater, D. E. Bunker, B. E. Benson, and M. S. Reid (1997). Tree-ring dating the 1700 Cascadia earthquake, *Nature* **389**, no. 6654, 922–923.
- Yeck, W. L., D. R. Shelly, K. Z. Materna, D. E. Goldberg, and P. S. Earle (2023). Dense geophysical observations reveal a triggered, concurrent multi-fault rupture at the Mendocino Triple Junction, *Commun. Earth Environ.* **4**, no. 1, 94.

- Yousefi, M., G. Milne, S. Li, K. Wang, and A. Bartholet (2020). Constraining interseismic deformation of the Cascadia subduction zone: New insights from estimates of vertical land motion over different timescales, *J. Geophys. Res. Solid Earth* **125**, no. 3, e2019JB018248, doi: [10.1029/2019JB018248](https://doi.org/10.1029/2019JB018248).
- Zandt, G., and E. Humphreys (2008). Toroidal mantle flow through the western U.S. slab window, *Geology* **36**, 295–298, doi: [10.1130/G24611A.1](https://doi.org/10.1130/G24611A.1).

Authors and Affiliations

Diego Melgar: University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0001-6259-1852>; **Amanda M. Thomas:** University of California, Davis, California, U.S.A.; **Valerie Sahakian:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0002-3278-4458>; **Pieter-Ewald Share:** Oregon State University, Corvallis, Oregon, U.S.A., <https://orcid.org/0000-0001-6674-1491>; **Andrew Meigs:** Oregon State University, Corvallis, Oregon, U.S.A., <https://orcid.org/0000-0003-2383-8853>; **Harold Tobin:** University of Washington, Seattle, Washington, U.S.A., <https://orcid.org/0000-0002-1447-6873>; **Lydia Staisch:** U. S. Geological Survey, Portland, Oregon, U.S.A., <https://orcid.org/0000-0002-1414-5994>; **Timothy Melbourne:** Central Washington University, Ellensburg, Washington, U.S.A., <https://orcid.org/0000-0003-1870-3962>; **Jill Elizabeth:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0009-0003-9003-0982>; **Rasheed Ajala:** Columbia University, New York, U.S.A., <https://orcid.org/0000-0001-5650-8362>; **Colin Amos:** Western Washington University, Bellingham, Washington, U.S.A.; **Loic Bachelot:** University of Oregon - CRESCENT, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0003-0711-8581>; **Scott Bennett:** U. S. Geological Survey, Portland, Oregon, U.S.A., <https://orcid.org/0000-0002-9772-4122>; **James Biemiller:** U. S. Geological Survey; Geology, Minerals, Energy and Geophysics Science Center, Portland, Oregon, U.S.A., <https://orcid.org/0000-0001-6663-7811>; **Brian Boston:** Auburn University, Auburn, Alabama, U.S.A.; **Joseph Byrnes:** University of Texas, Dallas, Texas, U.S.A., <https://orcid.org/0000-0002-6161-399X>; **Andy Clifford:** Cascadia Region Earthquake Science Center (CRESCENT), Eugene, Oregon, U.S.A.; **Brendan Crowell:** The Ohio State University, Columbus, Ohio, U.S.A., <https://orcid.org/0000-0001-7096-601X>; **Jonathan Delph:** Purdue University, Lafayette, Indiana, U.S.A., <https://orcid.org/0000-0002-3256-9301>; **Benchun Duan:** Texas A&M University, College Station, Texas, U.S.A.; **Eric Dunham:** Stanford University, Stanford, California U.S.A., <https://orcid.org/0000-0003-0804-7746>; **Tina Dura:** Virginia Tech, Blacksburg, Virginia, U.S.A.; **Hanna Elston:** Smith College, Northampton, Massachusetts, U.S.A., <https://orcid.org/0000-0002-2420-5241>; **Brittany Erickson:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0001-9457-8572>; **Shannon Fasola:** Cascadia Region Earthquake Science Center (CRESCENT), Eugene, Oregon, U.S.A., <https://orcid.org/0000-0003-3941-4828>; **Rebecca Fildes:** Western Washington University, Bellingham, Washington, U.S.A., <https://orcid.org/0000-0002-5210-5205>; **Alice Gabriel:** Scripps Institution of Oceanography UCSD, La Jolla, California, U.S.A., <https://orcid.org/0000-0003-0112-8412>; **Alex Grant:** U. S. Geological Survey, Seattle, Washington, U.S.A., <https://orcid.org/0000-0002-5096-4305>; **Alexandra Hatem:** U. S. Geological Survey,

Golden, Colorado, U.S.A., <https://orcid.org/0000-0001-7584-2235>; **Andrea Hawkes:** UNCW, Willmington, North Carolina, U.S.A., <https://orcid.org/0000-0003-1772-3865>; **Bin He:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0002-5994-1652>; **Eileen Hemphill-Haley:** Cal Poly Humboldt, Arcata, California, U.S.A., <https://orcid.org/0000-0002-6988-5906>; **Brenton Hirao:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0009-0007-3545-0983>; **Emilie Hooft:** University of Oregon, Eugene, Oregon, U.S.A., <https://orcid.org/0000-0002-1606-1057>; **Yihe Huang:** University of Michigan, Ann Arbor, Michigan, U.S.A., <https://orcid.org/0000-0001-5270-9378>; **Jesse Hutchinson:** Ocean Networks Canada, British Columbia, Canada; **Noel Jackson:** University of Kansas, Lawrence, Kansas, U.S.A., <https://orcid.org/0000-0002-9961-5608>; **Harvey Kelsey:** Cal Poly Humboldt, Arcata, California, U.S.A.; **Zoe Krauss:** University of Washington, Seattle, Washington, U.S.A., <https://orcid.org/0000-0002-5933-6823>; **Anna Ledecz:** University of Washington, Seattle, Washington, U.S.A., <https://orcid.org/0000-0002-0743-9409>; **Ben Leshchinsky:** Oregon State University, Corvallis, Oregon, U.S.A., <https://orcid.org/0000-0003-3890-1368>; **Yajing Liu:** McGill University, Montreal, Quebec, Canada, <https://orcid.org/0000-0002-5323-8077>; **Jack Loveless:** Smith College, Northampton, Massachusetts, U.S.A.; **Madeleine Lucas:** University of Washington, Seattle, Washington, U.S.A.; **William Marfo:** University of California, Davis, California, U.S.A., <https://orcid.org/0009-0003-0631-2750>; **Brett Maurer:** University of Washington, Seattle, Washington, U.S.A.; **Morgan Moschetti:** U. S. Geological Survey, Golden, Colorado, U.S.A., <https://orcid.org/0000-0001-7261-0295>; **Michael Olsen:** Oregon State University, Corvallis, Oregon, U.S.A., <https://orcid.org/0000-0002-2989-5309>; **Emily Roland:** Western Washington University, Bellingham, Washington, U.S.A.; **David Schmidt:** University of Washington, Seattle, Washington, U.S.A.; **Ignacio Sepulveda:** San Diego State University, San Diego, California, U.S.A., <https://orcid.org/0000-0002-7439-6613>; **Brandon Shuck:** Louisiana State University, Baton Rouge, Louisiana, U.S.A., <https://orcid.org/0000-0003-2543-721X>; **William Stephenson:** U. S. Geological Survey, Golden, Colorado, U.S.A., <https://orcid.org/0000-0001-8699-0786>; **Ashley Streig:** Portland State University, Portland, Oregon, U.S.A., <https://orcid.org/0000-0003-2622-2691>; **Ian Stone:** U. S. Geological Survey, Portland, Oregon, U.S.A., <https://orcid.org/0000-0002-9310-6132>; **Chih-Hsuan Sung:** Department of Civil and Environmental Engineering, UC Berkeley, Berkeley, California, U.S.A., <https://orcid.org/0000-0001-7606-0366>; **Daniel Trugman:** University of Nevada, Reno, Nevada, U.S.A., <https://orcid.org/0000-0002-9296-4223>; **William S. D. Wilcock:** School of Oceanography, University of Washington, Seattle, Washington, U.S.A., <https://orcid.org/0000-0001-7224-7246>; **Erin Wirth:** U. S. Geological Survey, Seattle, Washington, U.S.A., <https://orcid.org/0000-0002-8592-4442>; **Robert Witter:** U. S. Geological Survey, Anchorage, Alaska, U.S.A.; and **Emrah Yenier:** Haley & Aldrich, Portland, Oregon, U.S.A., <https://orcid.org/0000-0001-9516-3782>

Manuscript received 17 September 2025

Published online 10 July 2026