2024-2025 Twinning Program Research Projects

PROJECT 1: The tectonic significance of exhumed blueschist in the Hellenic subduction zone, Crete, Greece

Project Director:
Eirini Poulaki
Louisiana State University (Baton Rouge, LA)

Twin Mentor:
Carolyn Tewksbury-Christle
Fort Lewis College (Durango, CO)

Location Options for Academic Year: Remote or in-person at Louisiana State University or Fort Lewis College
Location Options for Summer: In-person at Louisiana State University or Fort Lewis College

Project Summary:
In modern subduction zones, the nature of the interface between the overriding and downgoing tectonic plates controls a whole host of processes, including earthquakes, plate speeds, and recycling into mantle. Subduction-related rocks that have been exhumed back to Earth's surface provide a window into these processes. The exhumation of subduction complexes has been divided into two end member processes: 1) as coherent slivers separated by thrust faults or 2) as mixed lithologies and metamorphic grades. The style of exhumation plays a key role in the larger-scale behavior of the interface (e.g., potentially controlling phenomena like episodic tremor and slow slip). The island of Crete in Greece is primarily composed of low grade metasedimentary rocks that subducted to ~20-40 km depth during the Oligocene and were brought back to the surface in the Miocene. Amongst these low grade rocks, blueschist and greenschist-facies rocks occur sporadically. These rarely exposed higher grade rocks are an enigma, and this research aims to answer the question: how were these higher grade rocks incorporated into the subduction interface and then exhumed in contact with rocks that don't preserve these assemblages anymore and/or are lower grade?

To answer this question, we draw on multiple geoscience disciplines, including structural geology, petrology, geochemistry, and geochronology. We are specifically working on mapping phases of deformation in these higher grade rocks using mineralogic assemblages, geochemical modeling, and microstructures, which together can determine the sequence of events. With these data and cutting-edge geochronology techniques, we can also put an age on different deformation phases, helping to better relate these higher grade and lower grade rocks. We will develop an explanation for why the blueschists commonly outcrop along a major tectonic contact and why these high pressure assemblages were well preserved during exhumation. Better understanding of how these rocks made it back to the surface can improve our understanding of on-going processes in modern subduction zones.

Role and probable activities for a student researcher in this project:
This research project will focus on characterizing the style of deformation associated with blueschist-facies rocks using a multidisciplinary structural and petrochronologic approach. We have already collected samples for this project and have targeted five blueschist samples. You will characterize mineral assemblages using petrography and will use microstructures to assess deformation histories within these rocks during the school year. With the mentors' guidance, you will pick targeted thin section locations for Scanning Electron Microscope (SEM), Electron Microprobe (EM), Electron Backscatter Diffraction (EBSD), and geochronology. You will use these data to investigate 1) mineral composition, which will help to better constrain the pressure-temperature (P-T) conditions of metamorphism, 2) the deformation of different mineral phases, 3) the timing of deformation and metamorphism. At the end of this project, you will be able to link your suite of data to the broader subduction zone processes responsible for exhuming these rocks. This project will be an excellent fit for a student that is excited to (a) learn more about structural geology and metamorphic petrology and geochronology and (b) gain hands-on experience in a variety of laboratory techniques. The strategic selection of the ~five blueschist samples will allow you to put together a concrete story about subduction zone processes and that would have large tectonic implications.

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<u>PROJECT 2: Active Fault Studies in Northern Oregon</u>

Project Director:
Ashley Streig
Portland State University (Portland, OR)

Twin Mentor:
Scott Bennett
U.S. Geological Survey (Portland, OR)

Location Options for Academic Year: In-person at Portland State University*,**
Location Options for Summer: In-person at U.S. Geological Survey*,**
**The USGS is on Portland State University's campus*
***The in-person option for this project is also open to students at other institutions in Portland, OR, such as the University of Portland and Lewis and Clark College.*

Project Summary:
Historically, few damaging earthquakes have occurred in the Pacific Northwest (PNW) region of the United States, although the region overlies the seismically active Cascadia Subduction Zone. Earthquake resilience efforts here have largely focused on the offshore Cascadia Subduction Zone and its potential for M 9 earthquakes. However, damaging earthquakes on onshore faults, such as the Portland Hills fault and Seattle fault, are also a poorly understood threat to the region. Many active faults have been previously identified onshore in Oregon, but new laser terrain imagery (lidar) has revealed several previously unknown active faults distributed across the landscape.

At the latitudes of the central PNW, the Cascade volcanic arc is defined by a lower relief ancestral Miocene arc in the western foothills of the Cascade Range and the high Cascades arc along the crest of the range. Wells and McCaffrey (2013) find clockwise rotation of 1°/My for the last 16 My in western Oregon and that the westward escape of the forearc and western Cascades (Oregon Coast block) creates new crust on the trailing edge of the rotating block (Wells and McCaffrey, 2013). Numerous N-S trending faults are visible in lidar through both the high and ancestral Cascade arc (e.g. Bennett et al., 2019; Madin et al., 2017) and preliminary paleoseismic and geologic mapping of these faults report evidence for late Quaternary and Holocene surface-rupturing earthquakes (Bennett et al., 2021; Madin et al., 2021). These active faults are likely relieving the Cascade intra-arc extension envisioned by Wells and McCaffery (2013) and Wells et al. (1998), which accommodates regional patterns of clockwise rotation. However, dozens of newly discovered fault strands remain unstudied. This research seeks to characterize these unstudied extensional faults in the high Central Cascades through a combination of paleoseismology, tectonic geomorphology, and geologic mapping.

REFERENCES CITED:
Madin, I.P., Streig, A.R., and Bennett, S.E.K., 2021, The Mount Hood fault zone, active faulting at the crest of the dynamic Cascade Range, north-central Oregon, USA, in Booth, A.M., and Grunder, A.L., eds., From Terranes to Terrains: Geologic Field Guides on the Construction and Destruction of the Pacific Northwest: Geological Society of America Field Guide 62, p. 49–71, https://doi.org/10.1130/2021.0062(03).

Madin, I. P., Streig, A. R., Burns, W. J., & Ma, L., 2017, The Mount Hood Fault Zone—Late Quaternary and Holocene Features Newly Mapped with High-resolution Lidar Imagery. Field-Trip Guide to Mount Hood, Oregon, Highlighting Eruptive History and Hazards: US Geological Survey Scientific Investigations Report 2017-5022-G, 100-109.

Bennett, S.E.K., Streig, A.R., Levinson, R., Roberts, N., Dunning, A., Wells, R., Madin, I., O'Connor, J.E., Reynolds, N.D., Pringle, P., and Grant, A.R, 2021, The Most Recent Earthquake on The Mount Hood Fault Zone, North-Central Oregon: Implications For Cascading Earthquake, Landslide, And Flood Multi-Hazards In The Columbia River Gorge, Geological Society of America Abstracts with Programs. Vol 53, No. 6, doi: 10.1130/abs/2021AM-370262. (IP-131500)

Bennett, S.E.K., Wells, R., Streig, A.R., Madin, I., and Stelten, M.E, 2019, Oblique Slip History of Active Faults Along the Western Margin of the Hood River Graben, North-Central Oregon, Geological Society of America Abstracts with Programs. Vol. 51, No. 4, doi: 10.1130/abs/2019CD-329235

Role and probable activities for a student researcher in this project:

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During the academic year a Portland State University (PSU) student researcher will work with Professor Streig (PSU) and the Active Tectonics Lab to learn and contribute to active fault studies. These activities will include ~bi-weekly one-on-one advising and background meetings with Professor Streig, participation in bi-weekly meetings to discuss readings and research with members of the PSU Active Tectonics Lab, and by mapping fault and geomorphic features in a GIS project. The student will learn to map surface fault expression and geomorphic units like glacial deposits using lidar derivatives, existing geologic maps, borehole, gravity, and other data in a GIS. During Winter term, the student will participate in discussions with Professor Streig and Dr. Bennett (USGS) regarding USFS permit applications to access field sites and collect sediment cores, rock samples, and potentially excavate a paleoseismic trench during summer 2025. Our goal is to expose a student to the research sequence ranging from site identification, requesting permits, field data collection, and prioritizing field samples for laboratory analysis.

During the summer, the student will intern at the U.S. Geological Survey, Portland office, located on PSU campus. The student will assist with geologic mapping and field data collection in the Columbia River Gorge region, where active faults in the high Cascades cut Quaternary volcanic and glacial deposits. This field work will include hiking off trail in steep, densely-vegetated terrain, learning to map geologic structures, geologic contacts, and geomorphic features related to the neotectonic evolution of the Columbia River Gorge. The student will also assist with collection of auger core transects across active faults, describing Quaternary volcanic, glacial, and sedimentary units, and collecting geochronological samples to constrain the timing of slip on the faults. Sample collection will likely include bulk rock samples for Cosmogenic surface exposure ages, rock samples for geochemical analysis and Ar/Ar eruption ages, and charcoal and other organic material for 14C dating of young faulted sediments. Mentors Streig and Bennett will work with the student to identify a small-sub project on a section of a fault for their focused investigation. This sub-project will involve remote mapping in a GIS and later field verification and investigations. The student will attend a major scientific conference where they will present the results of their sub-project.

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PROJECT 3: A 175-year record of vertical land motion in the Coos Bay, Oregon area from repeated leveling and tide gauge records, to characterize Cascadia strain and sea level rise.

Project Director:
Win McLaughlin
Southwestern Oregon Community College (Coos Bay, OR)

Twin Mentor:
Ray Weldon
University of Oregon (Eugene, OR)

Location Options for Academic Year: In-person at Southwestern Oregon Community College
Location Options for Summer: In-person at University of Oregon

Project Summary:
One of the key issues in Cascadia earthquake hazards is the rate and spatial distribution of strain accumulating on the subduction zone interface. The most critical component of this strain is vertical movement which can be determined from tide gauges, repeated leveling between stable benchmarks, GPS and InSAR. Because high precise GPS sites are too sparse and GPS and InSAR records too short, only a combination of sea level changes from long-term tide gauge and connected leveling records of tilt between benchmarks provide adequate spatial and temporal resolution to usefully constrain the subduction interface. The Coos Bay area on the central Oregon coast provides a unique setting to assemble and analyze this data because it has the oldest tide gauge in Oregon (at Empire from 1850-1870), a currently operating NOAA tide gauge (at Charleston since 1970) and numerous historical temporary gauges at North Bend and Coos Bay. There are numerous high-order leveling surveys along both NS and EW roads and railroad lines that connect the tide gauges and span the critical area above the base of the locked portion of the subduction zone where the strain gradient is greatest (Burgette et al. 2009).

This project will assemble the historic records of water levels, leveling connecting tide gauges to benchmarks (BMs), other leveling connecting benchmarks from NOAA, NGS and commercial surveying efforts and analysis of this data to determine a network of points with the velocity of vertical motion and uncertainties. Because BMs have finite lifetimes and tidal, highway, railroad and commercial BMs are often not connected, so overlapping surveys must be found or carried out to connect all the data so such long-term records are rarely assembled (Foster 2012; Talke & Jay, 2013). In addition, tide gauge records from different sites within the broader Coos/Charleston Bay area respond differently to tides, seasons, El Nino and other cycles, so short records need to be normalized to compare long-term trends. In addition to characterizing subduction zone strain this project will document the spatial distribution of vertical land movement so that relative sea level change associated with global sea level rise can be determined for coastal planning.

Burgette, R.J., Weldon, R.J.II, and Schmidt, D.A., 2009, Interseismic uplift rates for western Oregon and along-strike variation in locking on the Cascadia subduction zone, J. Geophys. Res., 114, B01408.

Foster, J., 2012, Appendix D, Long-Term Tide-Gage Stability from Leveling Data, In National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Talke, S.A. and Jay D.A., 2013, Nineteenth Century North American and Pacific Tidal Data: Lost or Just Forgotten? Journal of Coastal Research, 29 (6A). p. 118-127.

Role and probable activities for a student researcher in this project:
Students, under supervision of Professors McLaughlin and Weldon and with help from Reed Burgette of Department of Geology and Mineral Industries (DOGAMI) and Nicholas Weldon of Southwestern Oregon Community College will 1) track down (mostly online but may require trip to NOAA/NGS), make digital records, assemble and relate the needed water and leveling records to determine vertical velocities, 2) find and conduct 1st order leveling between current and historical BMs to tie together different data sets, 3) analyze the tide gauge records to normalize variations between different sites and, if needed, deploy short-term tide gauges (which Weldon has) to collect site specific data, and 4) make a map of the spatial distribution of vertical land movement for other CRESCENT researchers to model to characterize the subduction zone interface.

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PROJECT 4: Numerical models of Cascadia earthquake scenarios constrained by energy budget analyses

Project Director:
Elizabeth Madden
San Jose State University (San Jose, CA)

Twin Mentor:
Brittany Erickson
University of Oregon (Eugene, OR)

Location Options for Academic Year: In-person at San Jose State University
Location Options for Summer: In-person at University of Oregon

Project Summary:
Megathrust earthquakes pose a significant threat to lives and livelihoods in the Pacific Northwest of the United States. However, no large event has been recorded along the Cascadia subduction zone, as the last known earthquake occurred in 1700, before instrumentation. In this project, physics-based, high performance computing (HPC) models of potential Cascadia dynamic rupture scenarios will be generated to fill this data gap. In addition, we will analyze the energy budget of megathrust earthquakes. Prior to earthquakes, potential energy is stored as the rock strains under plate motions. During earthquakes, this energy is radiated as seismic waves, dissipated as heat, and spent to slip faults and fracture nearby rock. Calculating the energy budget components of the modeled Cascadia scenarios and comparing these results with energy budget components from both observations and HPC models of the 2004 Sumatra megathrust earthquake (Madden et al., 2022) provides a way to better constrain models of earthquake behavior across subduction zones and highlight potential seismic behavior at Cascadia.

Role and probable activities for a student researcher in this project:
The student researcher will run the Cascadia earthquake models using the open-source computational tool, SeisSol, on the high performance computing (HPC) platform provided by the San Diego Supercomputing Center through the HPC@MSI (high-performance computing at minority serving institutions) program. These models are ready to run, but the initial conditions will be determined by the student in consultation with the Project Director and Twin Mentor. During this process, the student will learn about earthquake physics and acquire the command line interface skills required to run the models through a remote computer connection. With the Project Director, the student will calculate the energy budget components across the suite of models and compare these results with energy budget components already determined from models (Madden et al., 2022) and with estimates from observations of the 2004 Sumatra earthquake.

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PROJECT 5: Dynamic triggering in volcanic systems in the Pacific Northwest

Project Director:
Aaron Velasco
University of Texas El Paso (El Paso, TX)

Twin Mentor:
Diego Melgar
University of Oregon (Eugene, OR)

Location Options for Academic Year: In-person at University of Texas El Paso
Location Options for Summer: In-person at University of Oregon

Project Summary:
Understanding the dynamics and deformation of the Cascadia subduction zone remains a key science driver for the Cascadia Region Earthquake Science Center (CRESCENT), and although the center does not necessarily focus on Cascadia volcanic systems, high-quality seismic data exist for several volcanoes above the subduction zone. Specifically, the Pacific Northwest Seismic Network (PNSN) in Oregon and Washington collects real-time seismic data for more than 3 seismic stations within 5 km of the following volcanic systems: Mt. St. Helens, Mt. Rainier, and Mt. Hood, Newberry Crater, and Crater Lake. The seismic network coverage allows for the location and monitoring of earthquakes and for investigation of the possible role of dynamic stresses (seismic waves from distant, large earthquakes) in changing the stress state of these volcanic systems. It has been observed that Alaska volcanoes are not susceptible to dynamic stresses (Prejean and Hill, 2018), yet little has been documented for the Cascadia volcanic systems. The student will investigate dynamic triggering, processing both catalog and waveform data from the PNSN. Expected results will include whether dynamic stress impacts these volcanic systems, and how sensitive these systems are to tectonic earthquakes.

Role and probable activities for a student researcher in this project:
This student will learn about collecting, processing, and analyzing seismic catalog and waveform data, learning the foundations of computation. They will work closely with UTEP mentor Aaron A. Velasco during the academic year, and then will complete this work at the University of Oregon with Diego Melgar. The student will conduct all aspects of this project.

PROJECT 6: Examining Slab-driven Mantle Flow in the Cascadia Subduction Zone

Project Director:
Margarete Jadamec
University of Buffalo (Buffalo, NY)

Twin Mentor:
Maureen Long
Yale University (New Haven, CT)

Location Options for Academic Year: Remote or in-person at University of Buffalo or Yale University
Location Options for Summer: In-person at University of Buffalo or Yale University

Project Summary:
Seismic observations that image the Earth's interior indicate that subduction zones are discontinuous, and, as such, each slab contains some form of lateral slab edge at each terminus. However, how slab-edges drive dynamic flow in the asthenosphere in subduction systems with natural complexity is still not well understood. The CRESCENT sponsored undergraduate researcher will focus on examining seismic data from Cascadia in the context of three-dimensional geodynamic models of the subduction zone that incorporate the natural geometric complexity of the slab and upper plate. In particular, the undergraduate researcher will examine shear wave splitting observations from the Cascadia system to constrain three-dimensional flow dynamics around the Cascadia slab edges predicted by the geodynamic modeling. This project is part of a larger initiative by PI Jadamec examining subduction dynamics and mantle flow along the Pacific Ring of Fire. Results from this project will shed light on slab-driven mantle flow dynamics in natural systems with implications for anomalous volcanism in the Pacific Ring of Fire. The project is also synergistic with an ongoing collaborative effort involving PI Long to combine insights from rock deformation, geodynamical modeling, and seismological observations to improve our understanding of subduction zone anisotropy.

Role and probable activities for a student researcher in this project:
The CRESCENT sponsored undergraduate researcher would compile and examine shear wave splitting observations for the Cascadia subduction zone, culminating in making maps in GMT or MATLAB, a table comparing previous studies, and writing a synthesis as a part of a larger project involving geodynamic modeling of subduction dynamics in Cascadia and along the Pacific Ring of Fire. The undergraduate researcher will work with a geodynamicist and seismologist for this integrative project and will gain research experience, learn practical and transferable programming skills, as well as deepen their domain science knowledge in seismology and geodynamics.