CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title:	**Developing machine learning tools to map active faults in bathymetry data**
Sponsor Information:	Donna Shillington, Professor, donna.shilington@nau.edu James Gaherty, Professor, james.gaherty@nau.edu Christine Regalla, Associate Professor, christine.regalla@nau.edu NAU School of Earth and Sustainability

Project Overview:

Overarching motivation: Offshore fault zones pose significant earthquake and tsunami hazards to coastal communities. The properties and distribution of these faults also provide important constraints on fundamental Earth processes, including chemical exchanges between the oceans and solid earth that occur due to faulting, the manner in which deformation occurs at plate tectonic boundaries, and more. Bathymetric (seafloor topography) data acquired from oceanographic research vessels can be used to map and characterize active faults that offset the seafloor. However, mapping of faults in these data is often done manually (e.g., Schottenfels & Regalla, 2021; Clarke et al., 2024), making it very time consuming and potentially inconsistent and/or incomplete. We propose that a CSS team could develop a code to use machine learning approaches to detect and characterize active faults in bathymetry data.

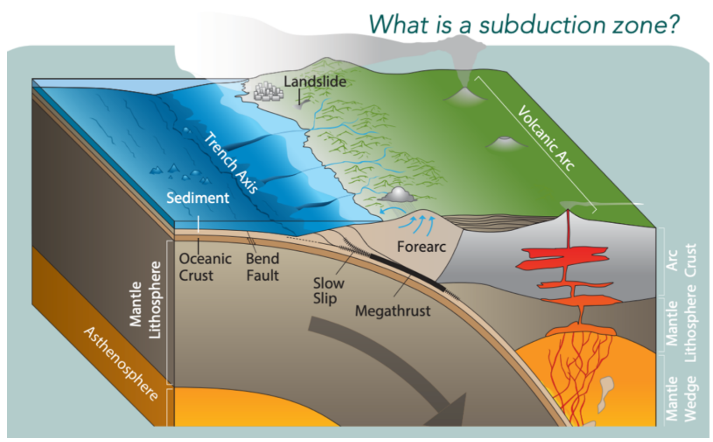

Figure 1: *Cartoon of a subduction zone, a type of plate tectonic boundary where an oceanic plate is thrust below another tectonic plate (From Hilley et al., 2022). The largest earthquakes and tsunami are generated on the megathrust, the boundary between the two plates, but other fault systems, including "bend faults" in the subducting plate are also hazardous and important for other fundamental processes.*

About the proposers: The proposers are geophysicists and geologists in the School of Earth and Sustainability whose research includes studies of subduction zones, where one tectonic plate is thrust beneath another (Fig. 1). These settings produce the largest and most destructive earthquakes and tsunami on Earth by slip on the megathrust, the main plate boundary fault (e.g., the 2011 magnitude 9 earthquake off Japan and the recent magnitude 8.8 earthquake off Kamchatka). Other faults in subduction zones can also pose significant hazards, including faults within both the subducting and overriding oceanic plates (Fig. 1). Donna Shillington is a geophysicist who examines controls on faulting and earthquakes at a number of subduction zones around the world, particularly the Alaska-Aleutian and Mexico subduction zones. Christine Regalla is a geologist who combines geological and geophysical data to examine faulting and earthquakes in subduction zones, particularly the Japan and Cascadia subduction zones. James Gaherty is a geophysicist who examines geodynamic processes involved in the creation and modification of oceanic plates, which subduct at subduction zones. All of these scientists are interested in improving methods to map faults in bathymetry data in both subduction zones and other geological settings.

The problem: Mapping faults in bathymetry data is often done manually by visual inspection of seafloor bathymetry maps and linear distance-height profiles extracted from such data (e.g., Schottenfels & Regalla, 2021; Clarke et al., 2024), making it very time consuming. Furthermore, mapping faults by hand could result in fault maps that are inconsistent and/or incomplete. Are all faults with similar lengths and/or scarp heights mapped? Is the mapping of faults more detailed in one area than another?

The solution: One possible solution is to develop an automated approach to identify and characterize faults. We propose that a CSS team could develop machine learning tools to map faults in bathymetric data. The ideal tool would either be a code (python, matlab, etc) or software package that loads bathymetry data from a given region and a training data set with examples of hand-interpreted faults from that region and identifies all faults in the study region. The unique identifying characteristic of these faults in bathymetry data are the abrupt changes in seafloor depth (often between 5-100 m) across them. Ideally, the results could be visualized in the software for QC purposes and exported as text files for analysis elsewhere. Optionally, this code could also calculate other attributes of the faults such as their orientation and the height of the seafloor scarp associated with them (although we already have other tools to do these calculations).

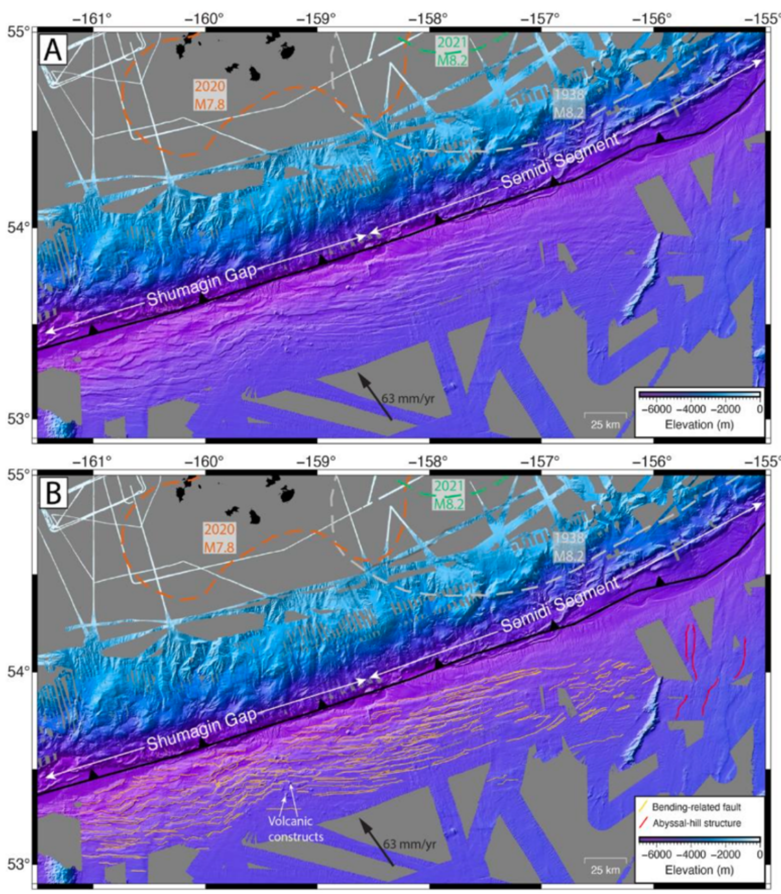

Figure 2*: A. Example of existing shipboard bathymetry data offshore of the Alaska Peninsula, where the Pacific plate is subducting beneath the North American plate. Black line shows where the plate boundary intersects the seafloor in the trench. Bathymetry is colored by depth and illuminated from the north. Grey areas show regions without data. Rupture areas of recent earthquakes also shown in colored dashed lines. B. Same as A, but with manual fault interpretations. Orange lines are interpreted faults in the incoming Pacific Plate. Red lines show examples of relic, inactive structures in the Pacific plate. (From Clarke et al., 2024)*

“Normal faults”, which form due to extension, generally have the simplest expression at the surface compared to other types of faults; they form quasi-linear scarps. Normal faults are abundant in subducting oceanic plates outboard of the subduction zone due to bending of the plate as it is thrust under the overriding plate, and thus can be seen in bathymetry data from these regions (e.g., Fig. 2). We think this setting provides an ideal test case for the development of a machine learning fault detection code. In particular, the project could use the Alaska subduction zone as a test case, where hand interpreted faults that could serve as the training set are available (e.g., Fig. 2; Clarke et al., 2024).

Anticipated impact: This methodology would enable much more efficient, detailed, and consistent mapping of fault systems in bathymetry data than is currently done and would thus open up significant scientific opportunities. The normal faults in the subducting oceanic plate that we propose as a focus of this project may influence the properties of the plate boundary fault at depth and thus its earthquake behavior (e.g., Shillington et al, 2015; Bassett et al, 2024). They are also thought to be pathways for seawater to infiltrate oceanic plates, enabling water to be carried into the deep Earth where it influences volcanism and many other processes (Ranero et al, 2003; Shillington et al, 2015). However, controls on the amount and style of this faulting remain poorly understood. With an automated machine learning tool such as we propose, it would be possible to map these faults at subduction zones around the world and undertake a much more comprehensive assessment of controls on this type of faulting and consequences for earthquakes and the deep water cycle. More generally, automated fault detection methods could be used in many other marine and terrestrial settings for hazard assessment and scientific study.

Knowledge, skills, and expertise required for this project:

- Familiarity with machine learning methods
- Some familiarity working with map / geospatial data would be advantageous
- Ideally, one of the team members may have taken an introductory geology class, but not required

Equipment Requirements:

- There should be no equipment or software required other than a development platform and software/tools freely available online.

Software and other Deliverables:

- A strong as-built report detailing the design and implementation of the product in a complete, clear and professional manner. This document should provide a strong basis for future development of the product.
- Complete professionally documented codebase, delivered both as a repository in GitHub, BitBucket, or some other version control repository; and as a physical archive on a USB drive.

References:

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Ranero, C. R., Phipps Morgan, J., McIntosh, K., & Reichert, C. (2003). Bending-related faulting and mantle serpentinization at the Middle America trench. *Nature*, *425*, 367-373.

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