My Fault! An investigation into earthquakes in Maryland

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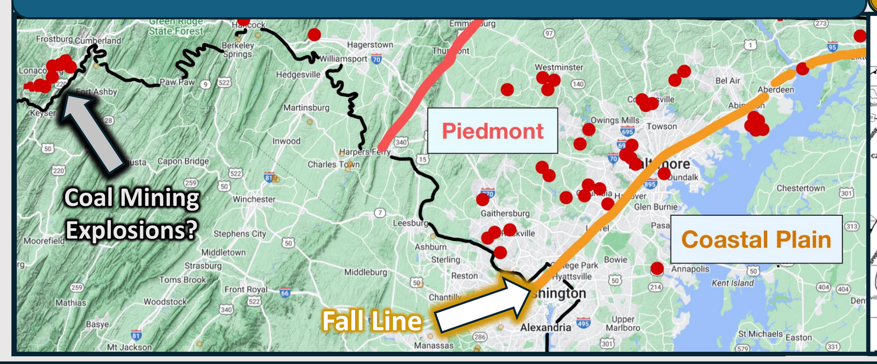
Introduction

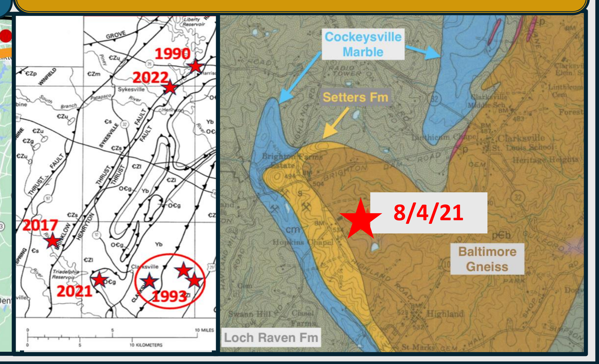
- Approximately 50 small earthquakes have occurred in Maryland since 1974 (about 1 a year)
- The causes of these earthquakes are unknown.
- This research examines 4 events in Baltimore and Clarksville (magnitudes ≤ 2.6) from 2021
- Formal geological maps do not show faults in these locations (see maps to right)
- The earthquakes in Maryland tend to occur along the Piedmont/Coastal Plain boundary (Fall Line)

Baltimore Events

Figure 1: Earthquakes in Maryland



Clarksville Events

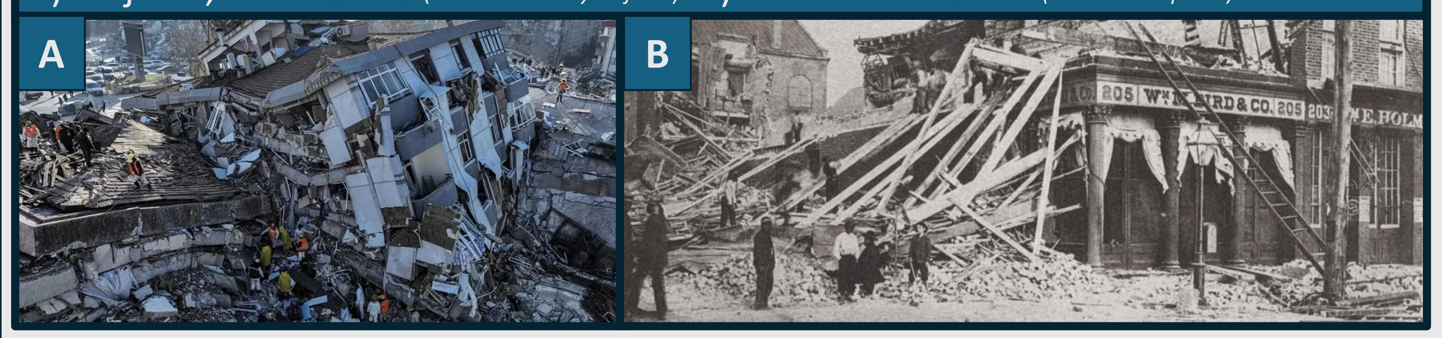


Motivation

Improving Knowledge of Seismic Hazard:

- Seismic Hazard assessment declares Maryland to be low risk . However, hazard assessment is based on knowledge of past seismicity and of faults, both of which are severely limited.
- The causes of earthquakes in the Eastern U.S. (EUS) are unclear, so hazard maps rely on faith that the present will inform the past.
- This work can help improve hazard assessment for other intraplate areas (e.g. Gujarat, Charleston) where deadly earthquakes are likely to occur.

Figure 2: Devastating intraplate earthquakes.
A) Gujarat, India 2001 *(source: Mid-day Gujarat)* B) Charleston 1886 *(source: Wikipedia)*



Explaining stress and seismicity in intraplate regions:

Considerable uncertainty exists about the state and sources of stress in the Eastern U.S. and in intraplate regions in general. This research can help answer some of these questions.

Hypothesis

- Fault planes of earthquakes are aligned within 15 degrees of the Fall Line.

Background

Distribution of earthquakes in the Eastern U.S.

- There are several established Seismic Zones: New Madrid (NMSZ), Western Quebec (WQSZ), and Eastern Tennessee (ETSZ) – Fig.2A
- Seismicity also clusters in a band along the Piedmont/Coastal Plain. Therefore, a diffuse PCSZ is proposed. This includes the 3 prominent clusters in Fig.2B as well as others.

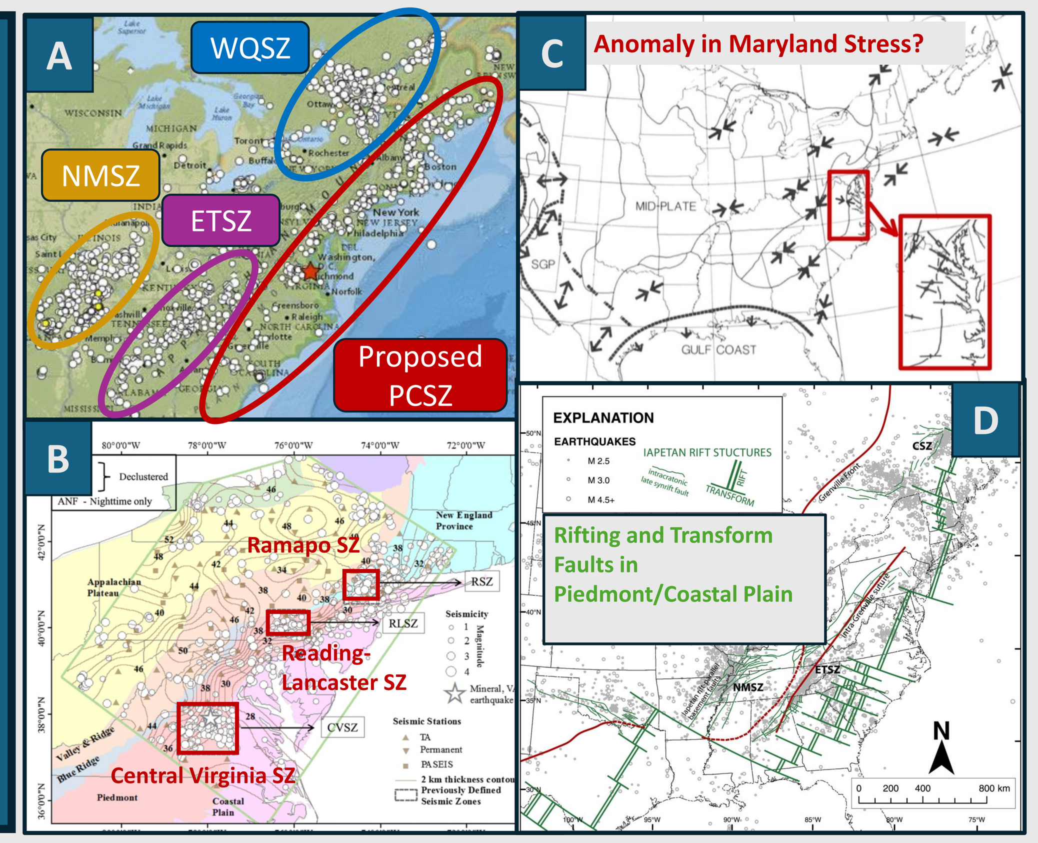
State of stress in the Eastern U.S.:

- A uniform NE–SW stress field appears across the EUS (Fig.2A) and is thought to be caused by tectonic forces at a distance
- Maryland has anomalous stress in some maps

Possible causes of stress and seismicity:

- Tectonic
- Gravity anomalies
- Moho gradient
- Isostatic
- Mantle anomalies
- Pore pressure
- Ancient rifting faults along the Piedmont (Fig.3D)

Figure 3:
A) Earthquakes in the EUS since 1973 with seismic zones (USGS Earthquake Hazards)
B) Seismic zones in the Central US. (Soto-Cordero et al., 2018)
C) The state of stress in the EUS (Zoback and Zoback, 1989)
D) Ancient faults vs seismicity. (Thomas and Powell, 2017)



Methods

How to find the focal mechanism of an earthquake

Data Collection: **Process Seismograms** → Forward Problem: **Find Green's functions** → Inverse Problem: **Focal Mechanism**

The Moment Tensor Equation

Forward ⟹ *Inverse*

$$\bar{d} = G * M \implies M = G^{-1} * \bar{d}$$

GOAL: We want the **moment tensor** (**M**), which encodes the motion at the source (strike, dip, rake, etc.). This is related to the displacement seismograms $\bar{d}$ by the moment tensor equation (box at top right). This equation must be inverted to get M

Solving the Forward Problem:

1) Seismograms from the IRIS Wilber3 database were instrument-corrected and filtered between 0.5 and 3 Hz.
2) **Green's functions** (**G**) must be found using a known focal mechanism (Germantown 2010) . Green's functions encode the response of the ground to earthquake motion. They are seismograms based on the best-fit velocity model.
3) A simple 1-D crustal model with 5 layers was used. A Python program permutated the most likely values of velocity and thickness (Fig.4). Fit by eye proved better than numerical methods. Fig.5 and Fig.6 show the current best fit model and corresponding seismograms. Fit decays with station distance.

Figure 4: Table of permutated values used in Python program. Model is based on an analysis of global crustal structure by Mooney (2015).

Layer	Thickness (km)	P-velocity (km/s)
Weathered	0.25,0.5,1,2,3,4	2,2.5,3,3.5,4,4.5,5,5.5
Upper Crust	5,7.5,10	5.5,5.75,6,6.25,6.5
Middle Crust	10,15,20	6.5,6.75,7
Lower Crust	$37 - z_1 - z_2 - z_3$	7,7.5
Upper Mantle	infinite	8

Figure 5: Current best fit crustal model from program (thickness to scale). See Figure 6 for best fit seismograms.

Weathered Layer: $Vp = 2.5\ km/s, z = 1km$

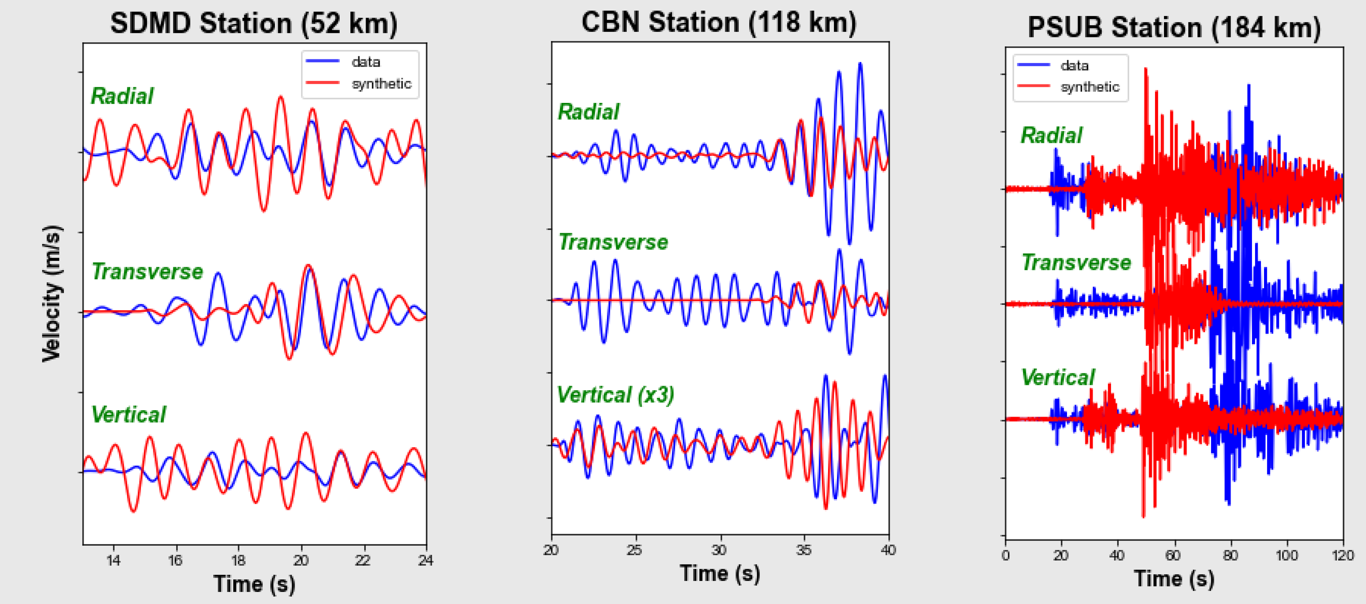
Upper Crust: $Vp = 6\ km/s, z = 5\ km$

Middle Crust: $Vp = 6.75\ km/s, z = 20\ km$

Lower Crust: $Vp = 7.5\ km/s, z = 11\ km$

Upper Mantle: $Vp = 8\ km/s, z = infinite$

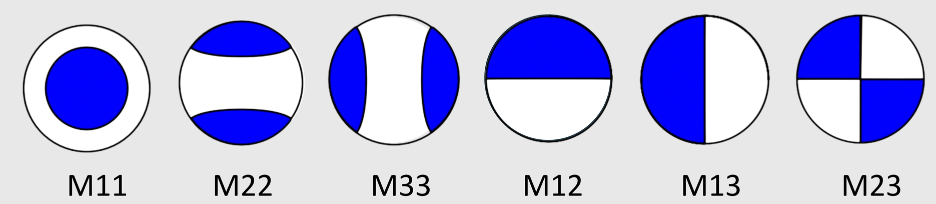
Figure 6: Current best fit synthetic seismograms from Python program showing decaying fit over distance.



Solving the Inverse Problem:

1) The best fit crustal structure is used to create **"fundamental" synthetic seismograms** (Green's functions) for each of the 6 independent components of the moment tensor (all Ms can be made from these)
2) The fundamental seismograms are are compiled into G, while all the real data is compiled into $\bar{d}$.
3) Because G is not square, the moment tensor equation is solved using **least squares inversion** (minimize the difference between $\bar{d}$ and $G * M$)
4) Focal mechanisms (FMs) are represented with **"beachball plots."**

Figure 7: The 6 fundamental focal mechanisms



Preliminary results

- ❑ The program was successfully tested using synthetic data and random error in the crustal model (Figure 8)
- ❑ A FM was calculated for the 2010 Germantown earthquake

Figure 8: Test of inversion: Seismograms for synthetic data vs. inversion with 20% max error

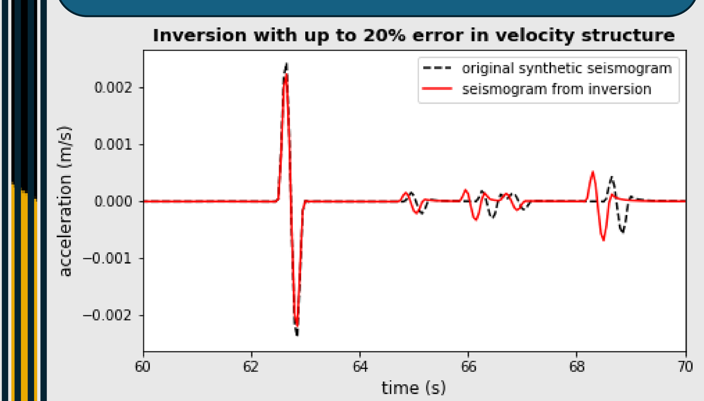
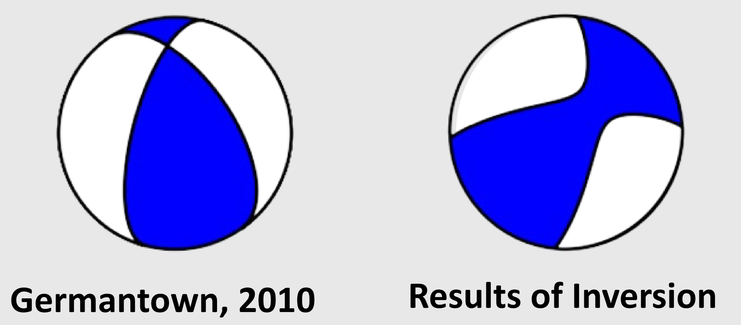


Figure 9: 1-station inversion for the 2010 Germantown event vs. the known focal mechanism. The fit is fairly good.



Future Work

- Improve fit of Green's functions
- Find focal mechanisms for all events (partially complete)
- Compare focal mechanisms to maps of local geology and stress
- Apply more rigorous uncertainty analysis