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SDRD
SITE-DIRECTED RESEARCH & DEVELOPMENT

Earthquake Location and Ground Motion Models

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Science & Technology Work-in-Progress Seminar, July 20, 2021

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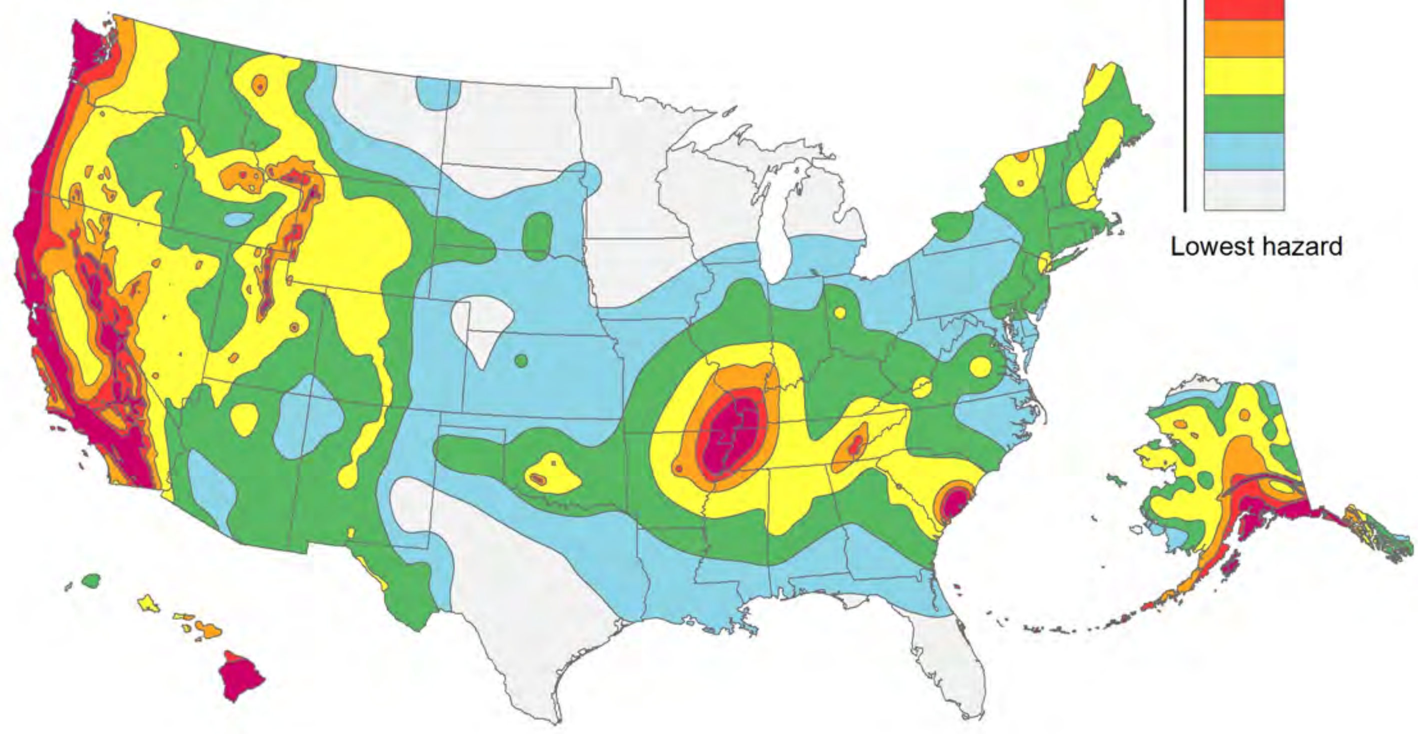
Earthquake Ground Motion Models

Motivations – Seismic Hazard

- National Seismic Hazard Map identifies regions of high seismic hazard
- Eastern California Shear Zone and Walker Lane into Reno region of high hazard



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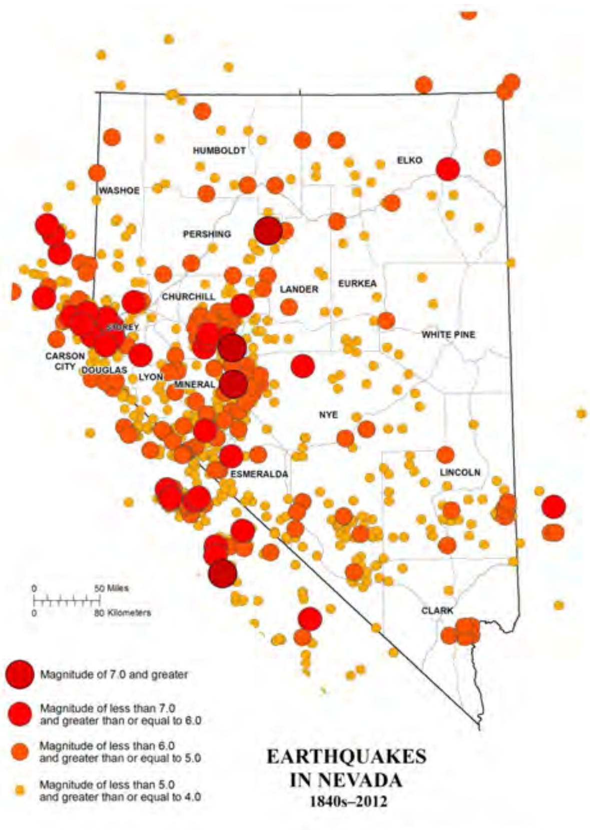
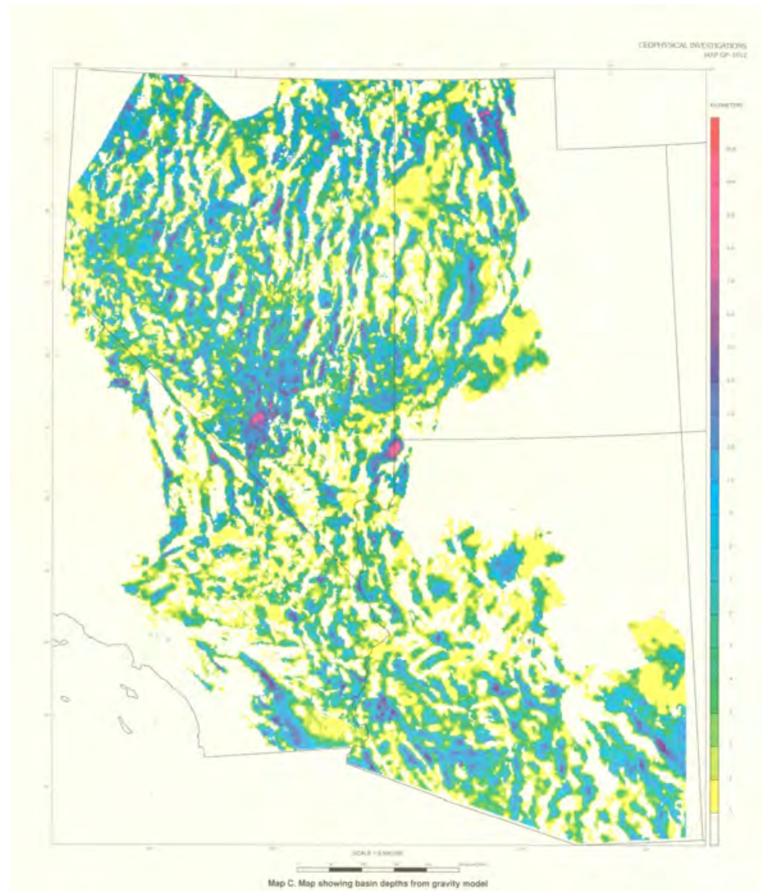
Motivations – Seismic Hazard

- Large faults and historic earthquakes adjacent to sedimentary basins and urban populations



Earthquakes in the Nevada region recorded from the1840s to 2012. (Nevada Seismological Laboratory)

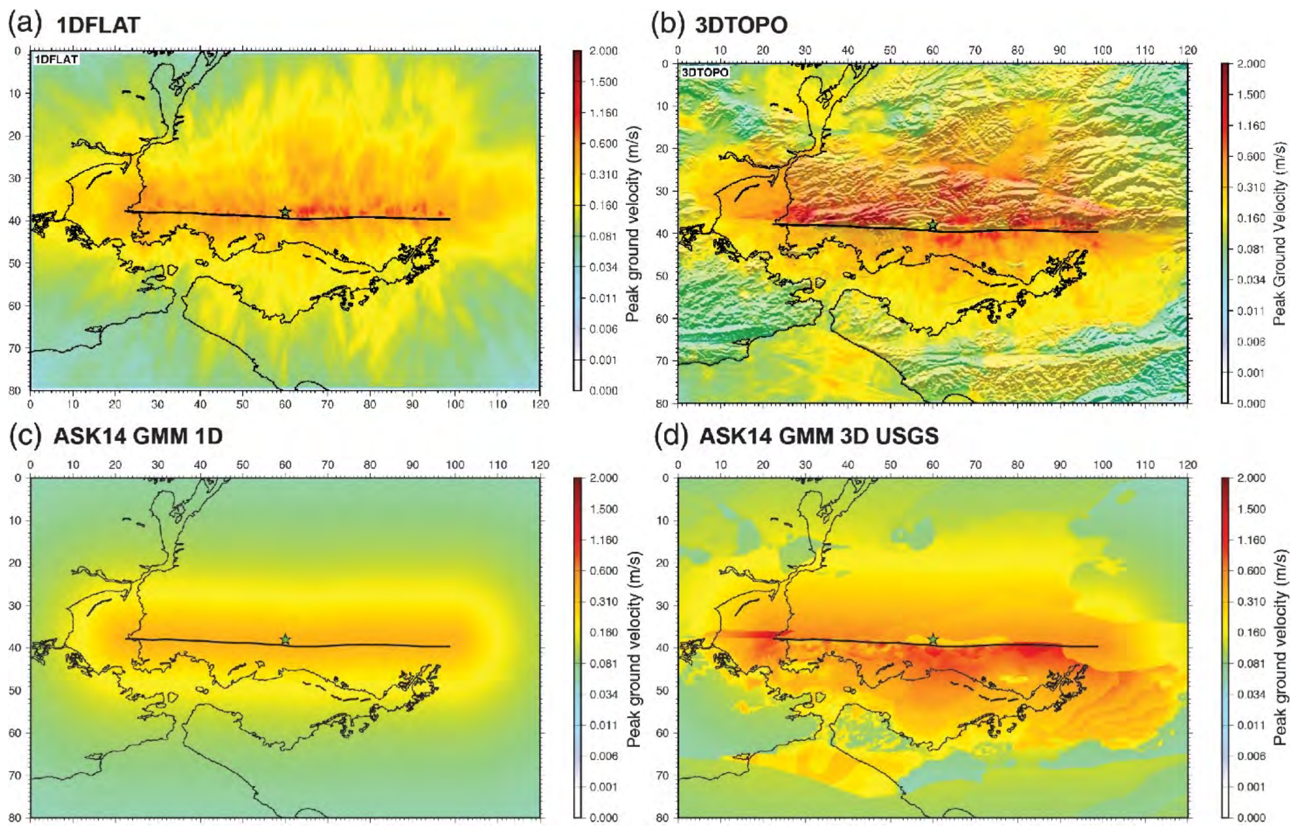
www.shakeout.org



Saltus & Jachens, 1995

Earthquake Ground Motion Modeling

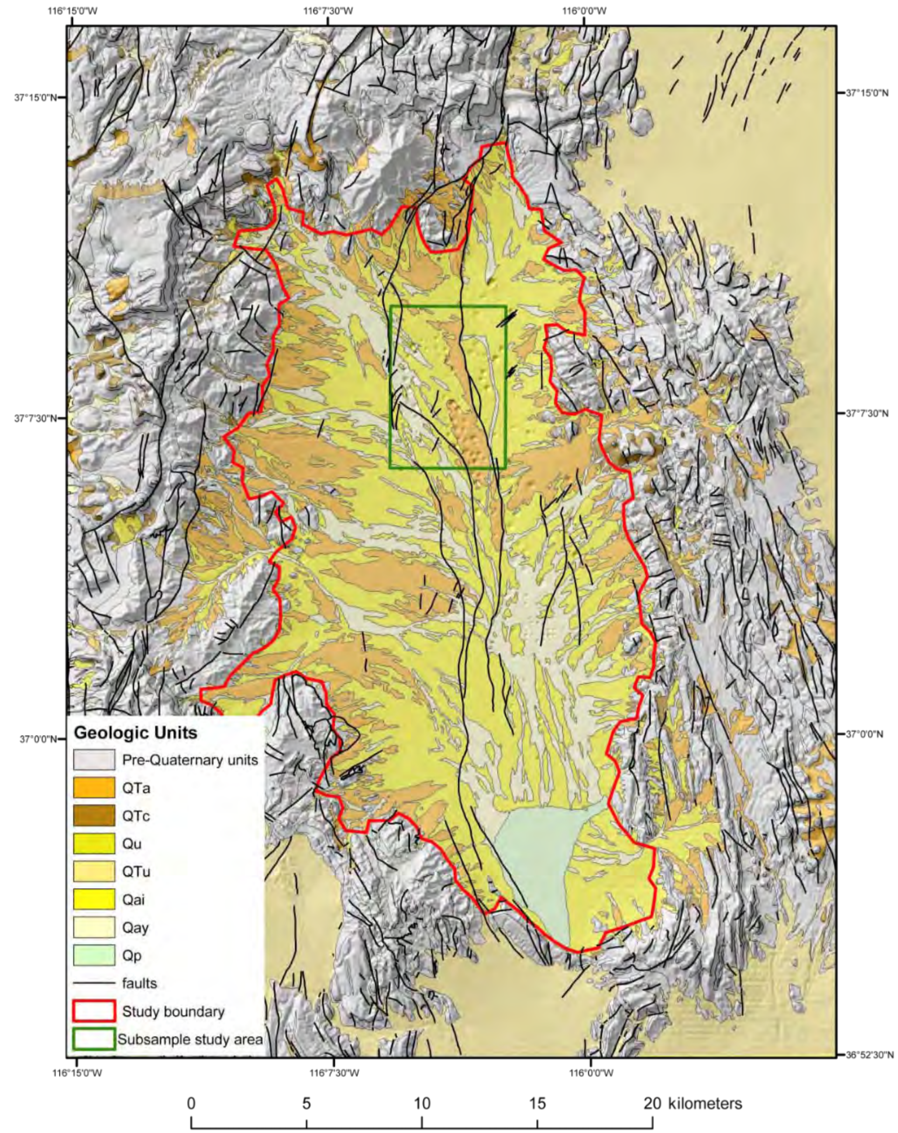
- HPC advancements have enabled simulations of ground motion through structurally complex 3D models
- Necessary to resolve 3D velocity models



PGV of M7.0 Hayward Fault earthquake simulations (Rodgers et al., 2019)

Seismic Risk at NNSS

- Long faults can produce large magnitude earthquakes
- Infrastructure in close proximity to these faults can experience strong seismic shaking
- Yucca Fault near NNSS critical infrastructure



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Objectives

- Develop an end-to-end modeling capability for strong ground motion simulations to use in seismic hazard assessment of critical facilities and infrastructure at the NNSS.

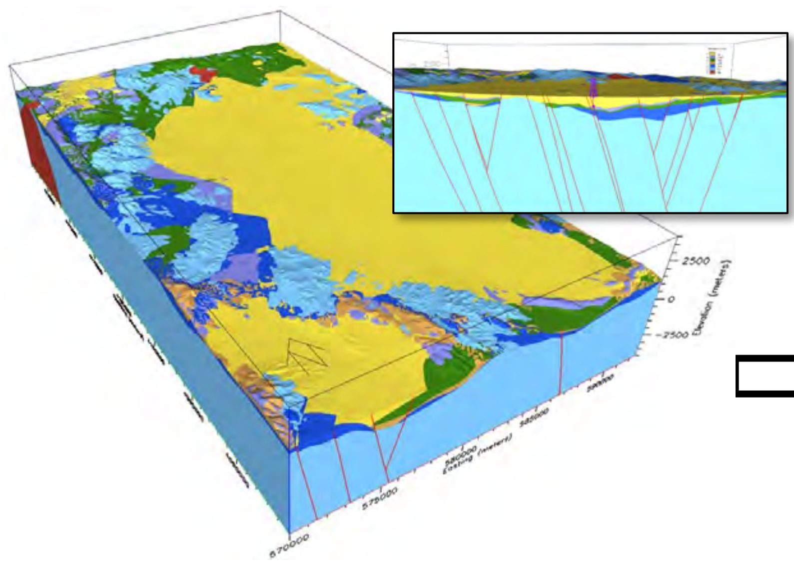
- Locate areas of high seismic hazard at the NNSS during earthquakes on Yucca Fault.

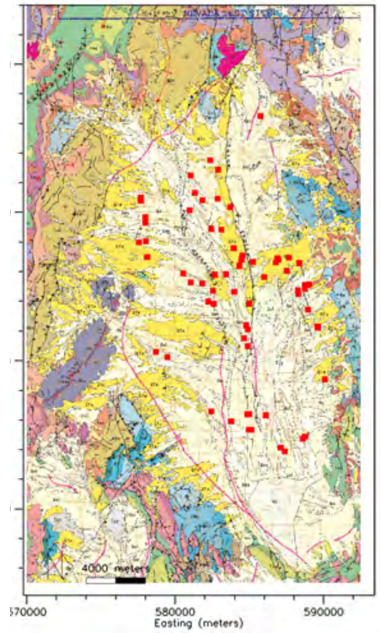
- Evaluate expected ground shaking levels for M6.5 potential earthquakes on the Yucca Fault at local facilities such as U1a.

- Produce and make available ground motion time histories that can be used to estimate the seismic response of critical facilities and infrastructure at NNSS.

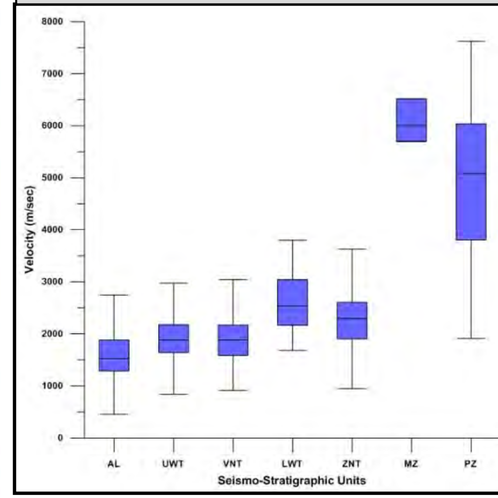
Yucca Flat Seismic Velocity Model

Geological Framework Model (GFM)

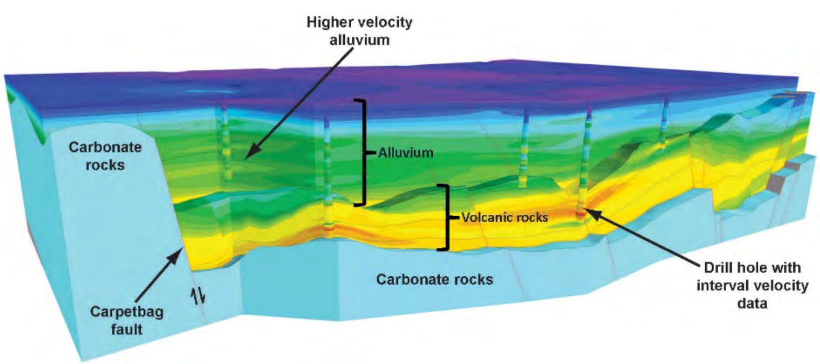




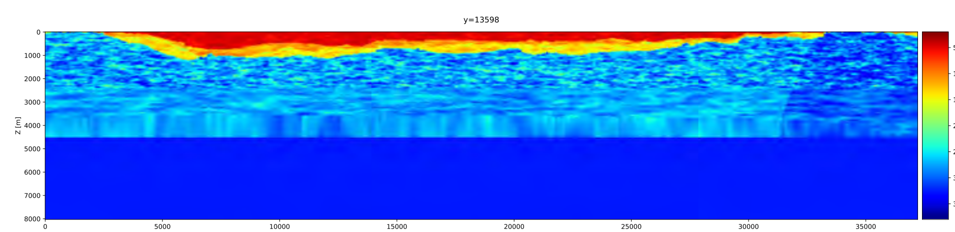
Velocity Values for GFM Layers



Shallow Geotechnical Layers



Stochastic SVM



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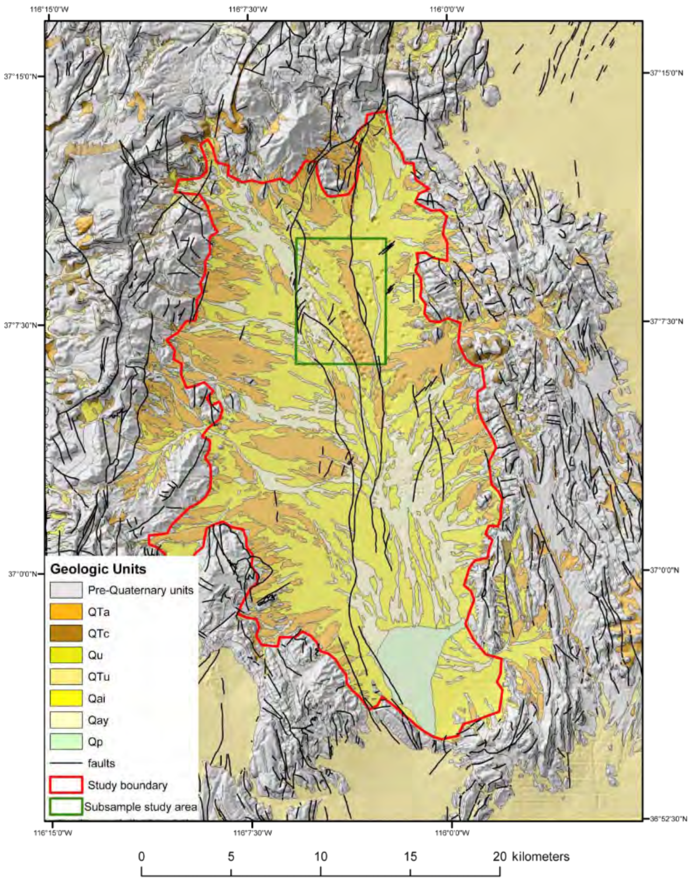
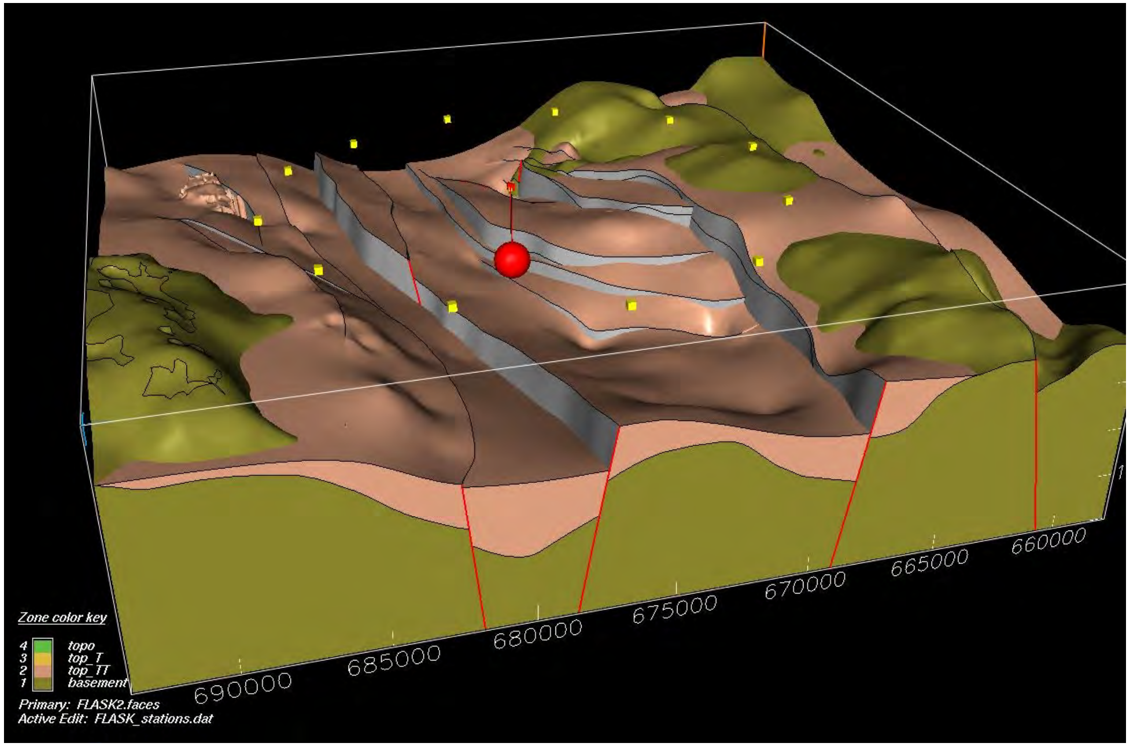
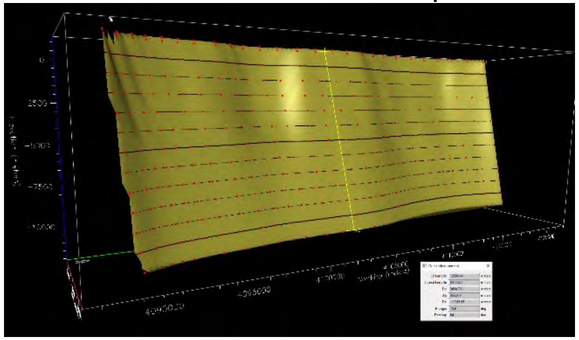
Yucca Fault Geometry

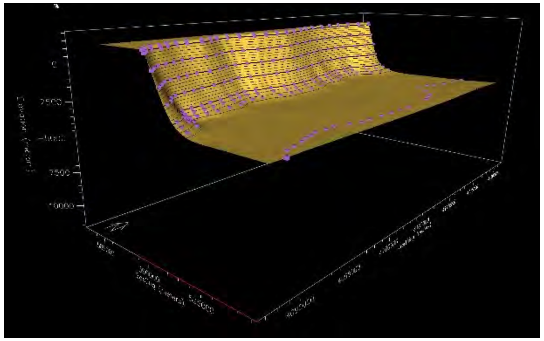


Mapped Faults in the Yucca Fault Basin



Proposed Fault Geometries



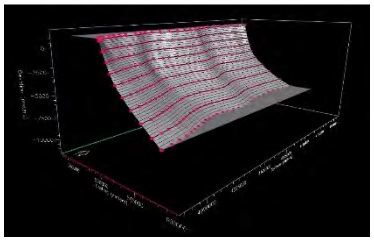


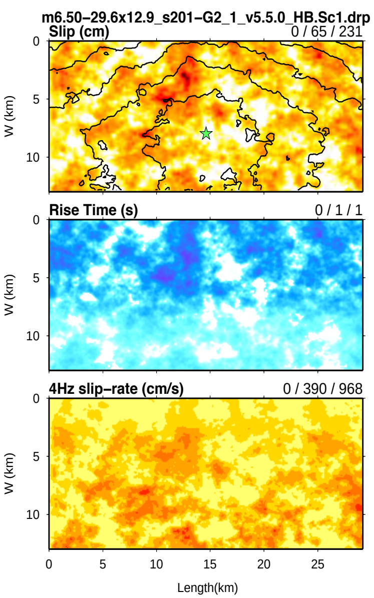
Provided by L. Prothro

M6.5 Bilateral Earthquake Rupture Scenarios

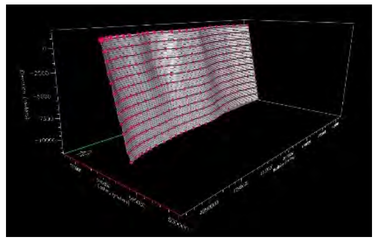
- Simulate rupture scenarios that vary geometry of Yucca Fault

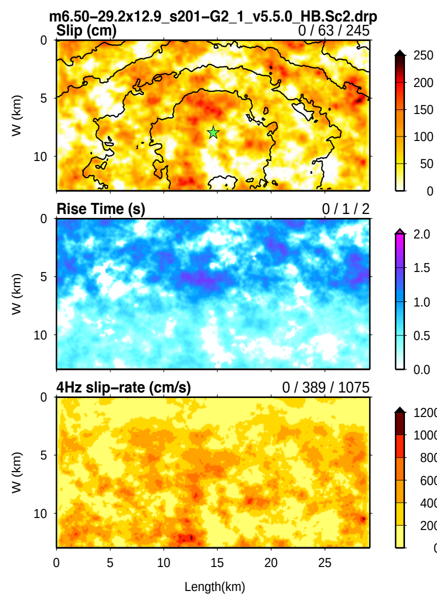
Scenario Sc1



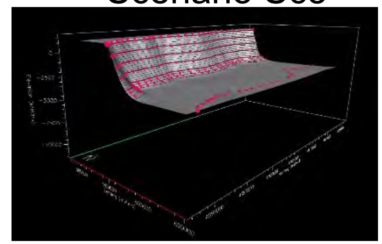


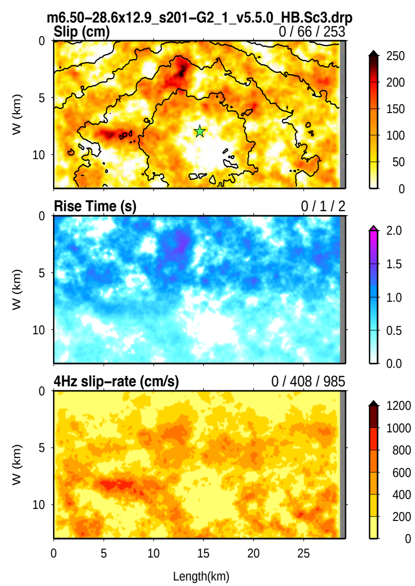
Scenario Sc2



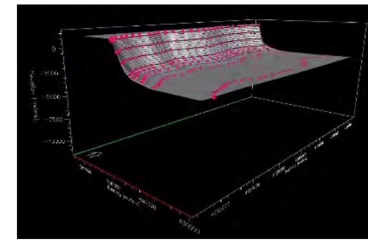


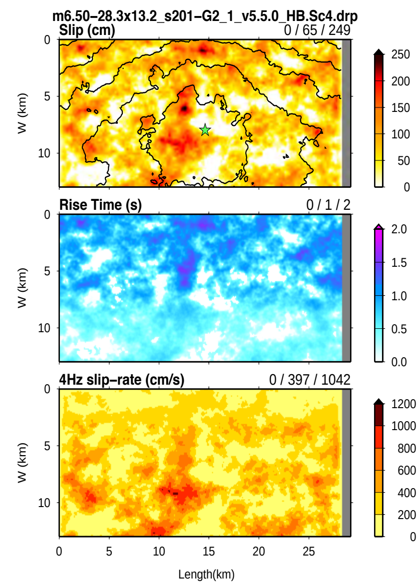
Scenario Sc3



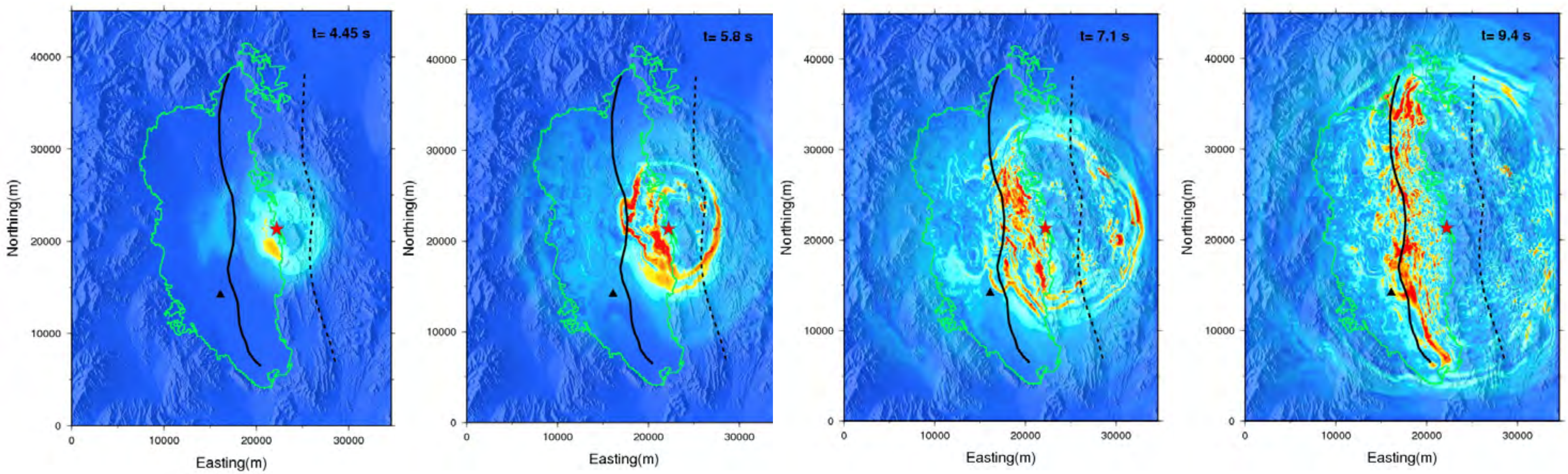


Scenario Sc4



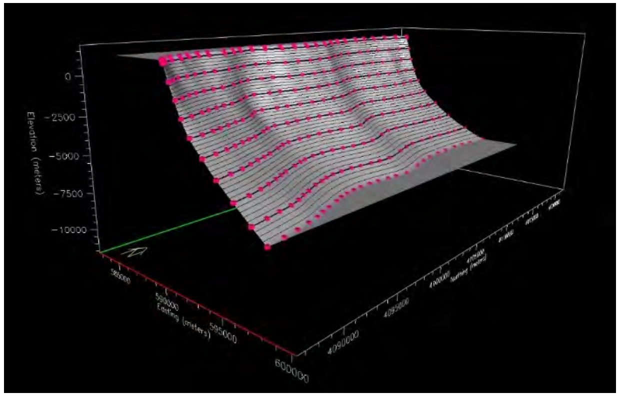


Snapshots of Simulated Ground Motion



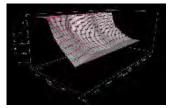
- Scenario computed from 0–5 Hz
- Strong ground motion near U1a
- Basin traps seismic waves

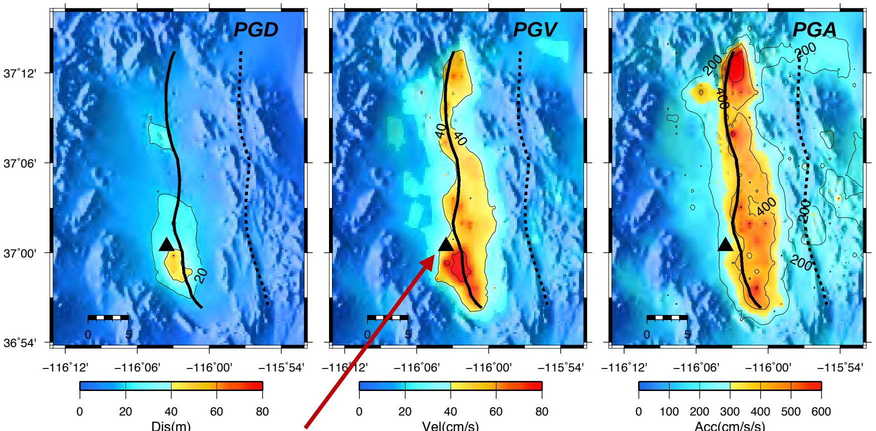
Fault Geometry Sc1



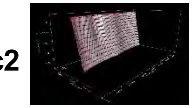
Simulated PGD, PGV, and PGA

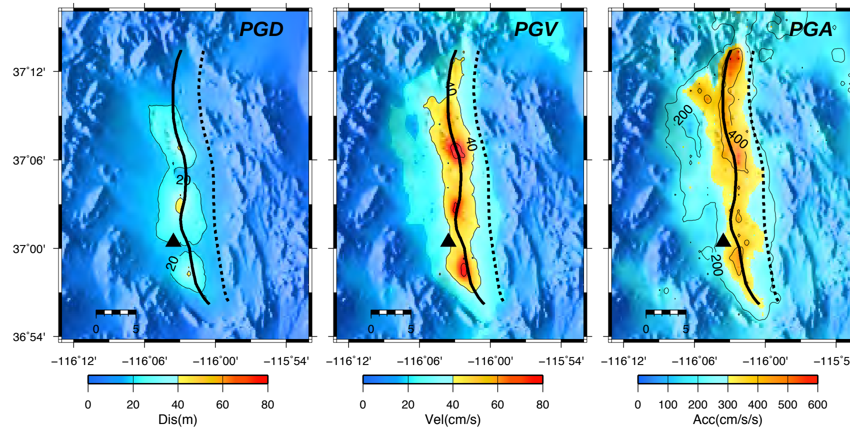
Scenario Sc1



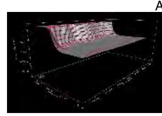


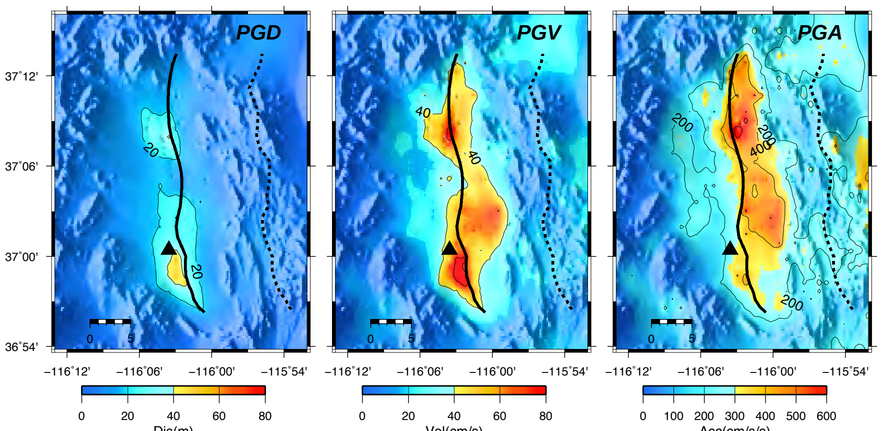
Scenario Sc2



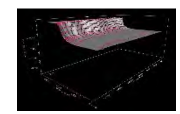


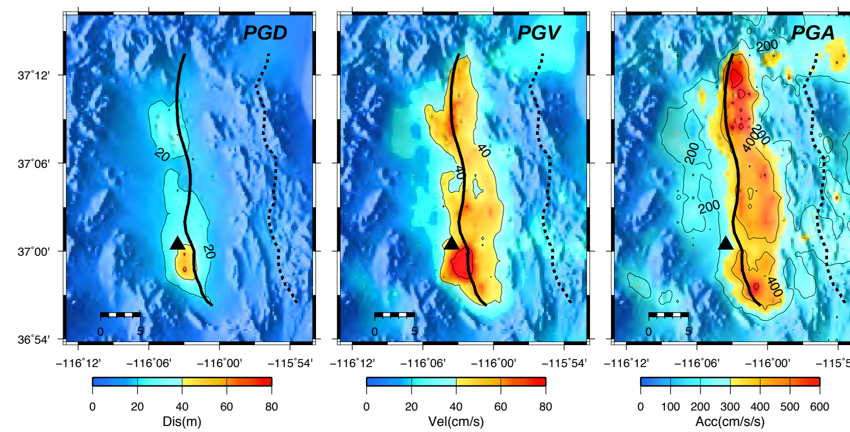
Scenario Sc3





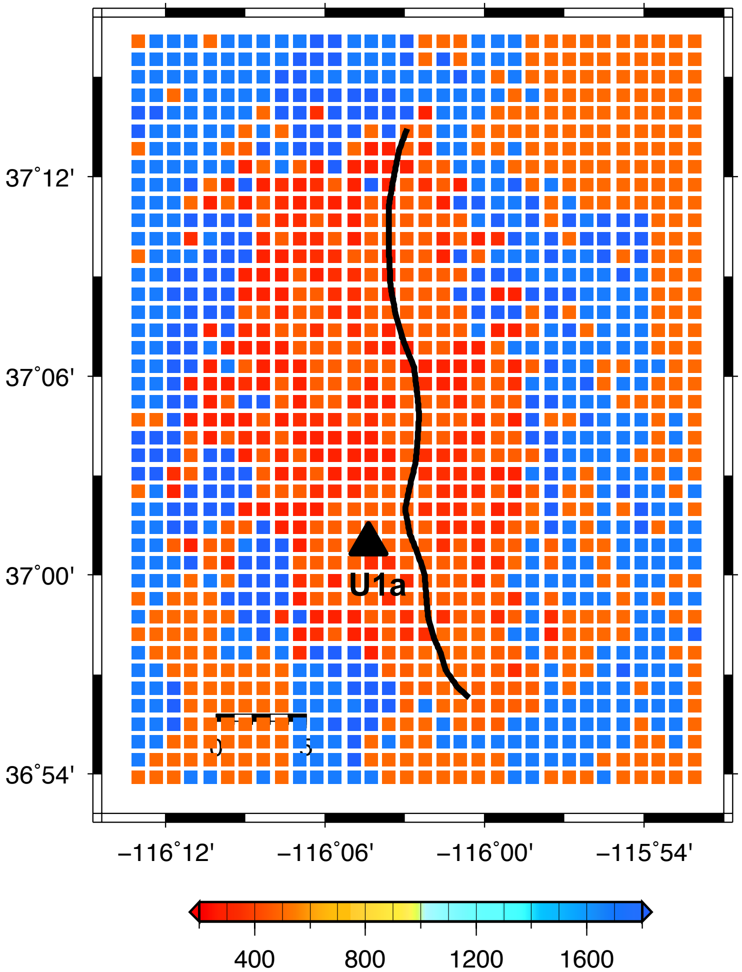
Scenario Sc4



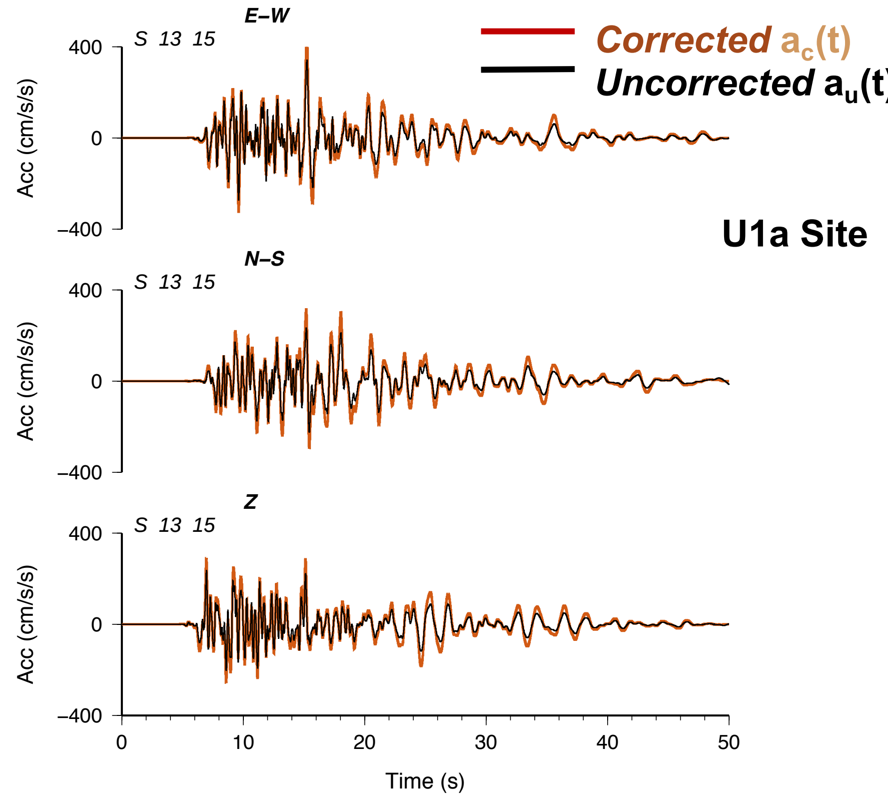


Site Effects Corrections

Vs_{30} Map



$a_c(w) = a_u(w) * S_{vs30}(w)$ → inv FFT: $a_c(t)$



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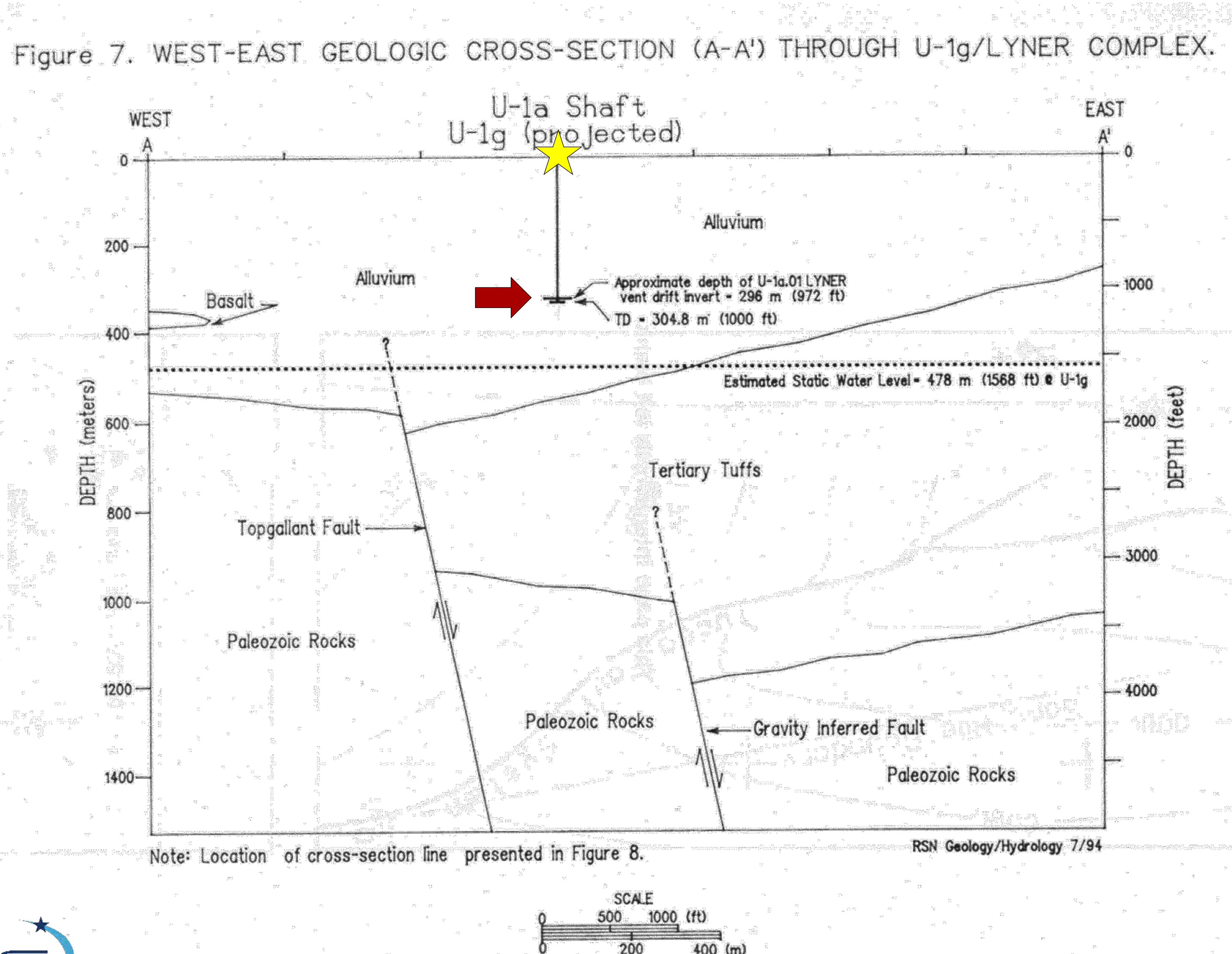
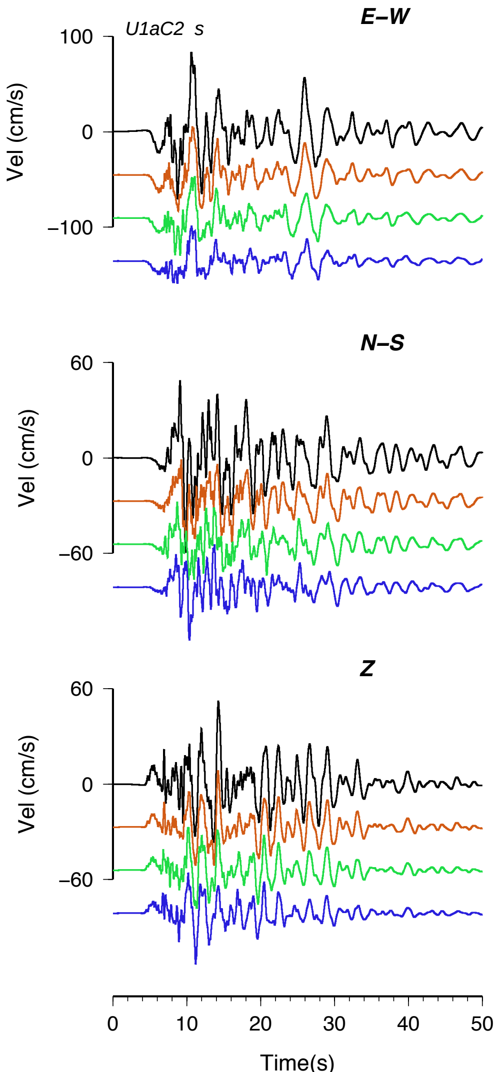
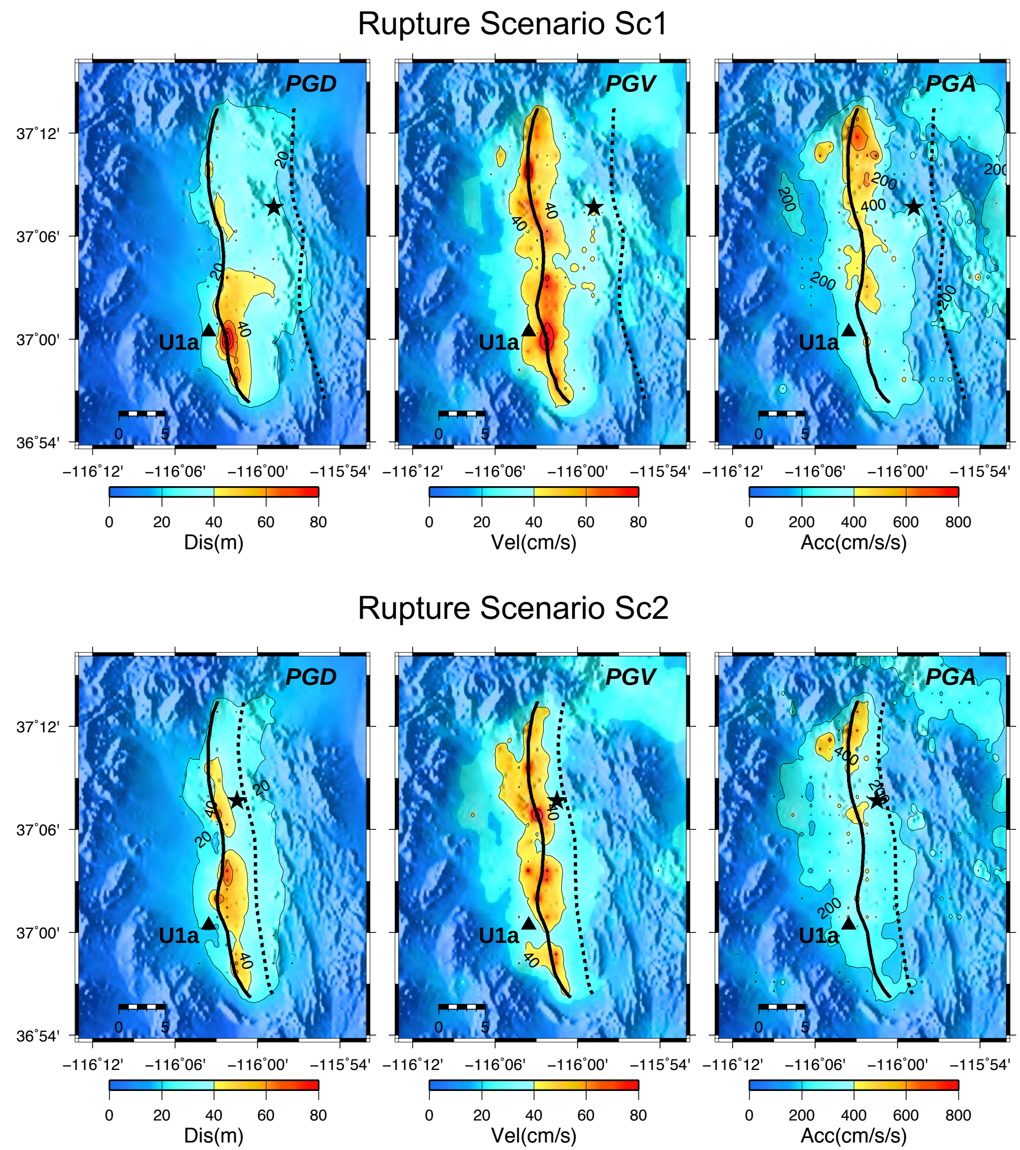
Take Modeling to Working Level of U1a



West-East Geologic Cross Section

Unilateral Rupture Scenarios



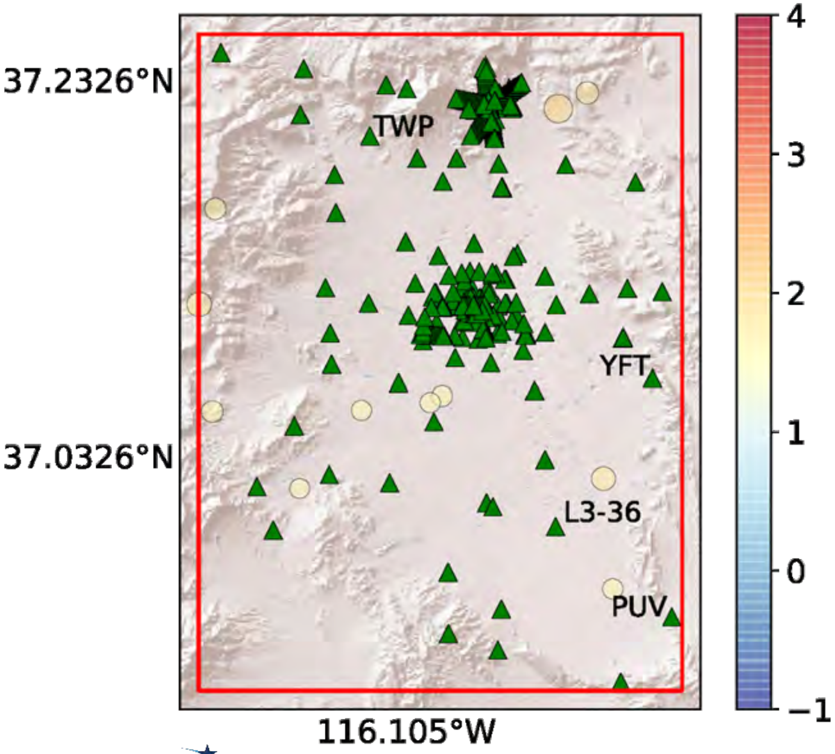


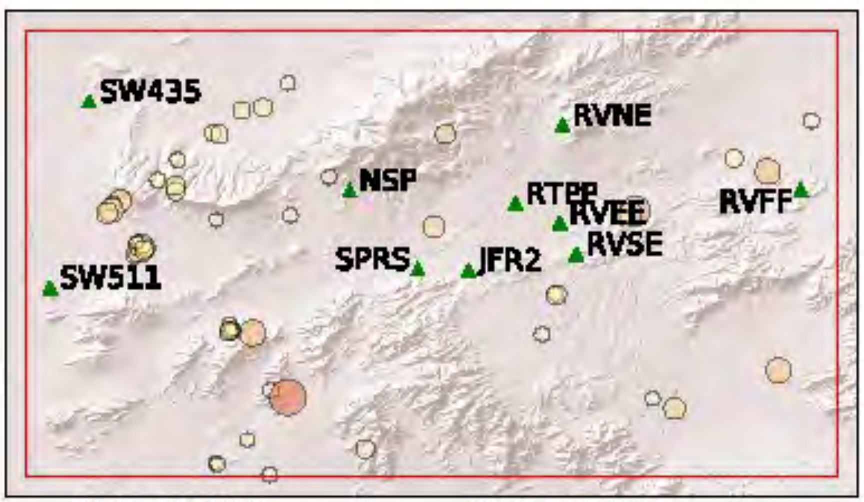
Conclusions

- Developed an end-to-end modeling capability for strong ground motion simulations to use in the seismic hazard assessment of critical facilities and infrastructure at the NNSS.
- Ground motion amplification in the Yucca Flat basin is controlled by the interactions of basin geometry with the Yucca Fault characteristics, including fault curvature and rupture initiation.
- The highest ground motion is observed along the fault trace and in the hanging wall region.
- Near-fault areas with deep sediments and those located on the hanging wall region are characterized by larger ground motion amplifications.
- Comparisons with Ground Motion Prediction Equations for normal faulting demonstrate that the simulated spatial amplification pattern is also affected by the fault curvature at depth.
- The effects of fault curvature at U1a site are more pronounced in the period range 1–3 s.
- Local shallow basin structure amplifies and increases the duration of ground motion in a small area south of U1a site.

Ongoing & Future Work

- Additional simulations are needed to evaluate the effects of unilateral rupture scenarios on ground motion at U1a
- Site response analysis
- Validate ground motion models with recorded events





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Earthquake Location Models

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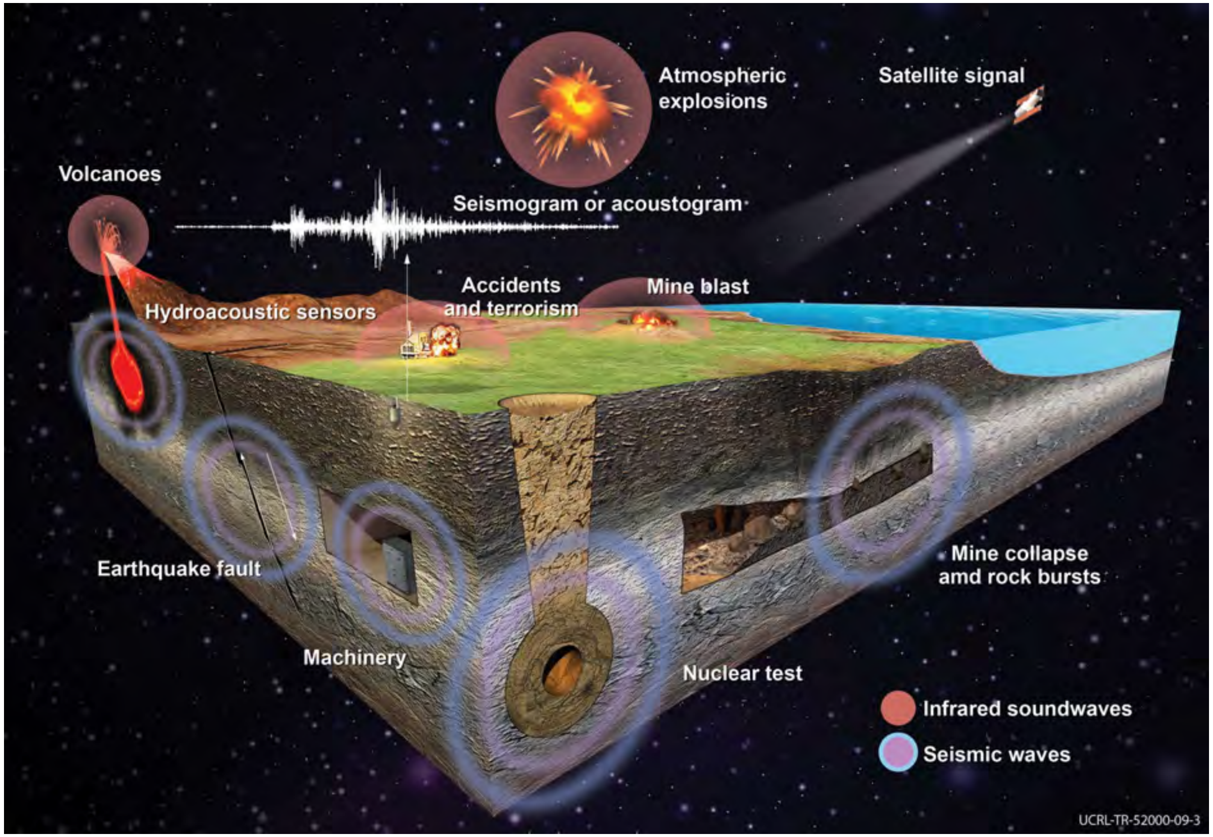
Motivation – Nuclear Explosion Monitoring

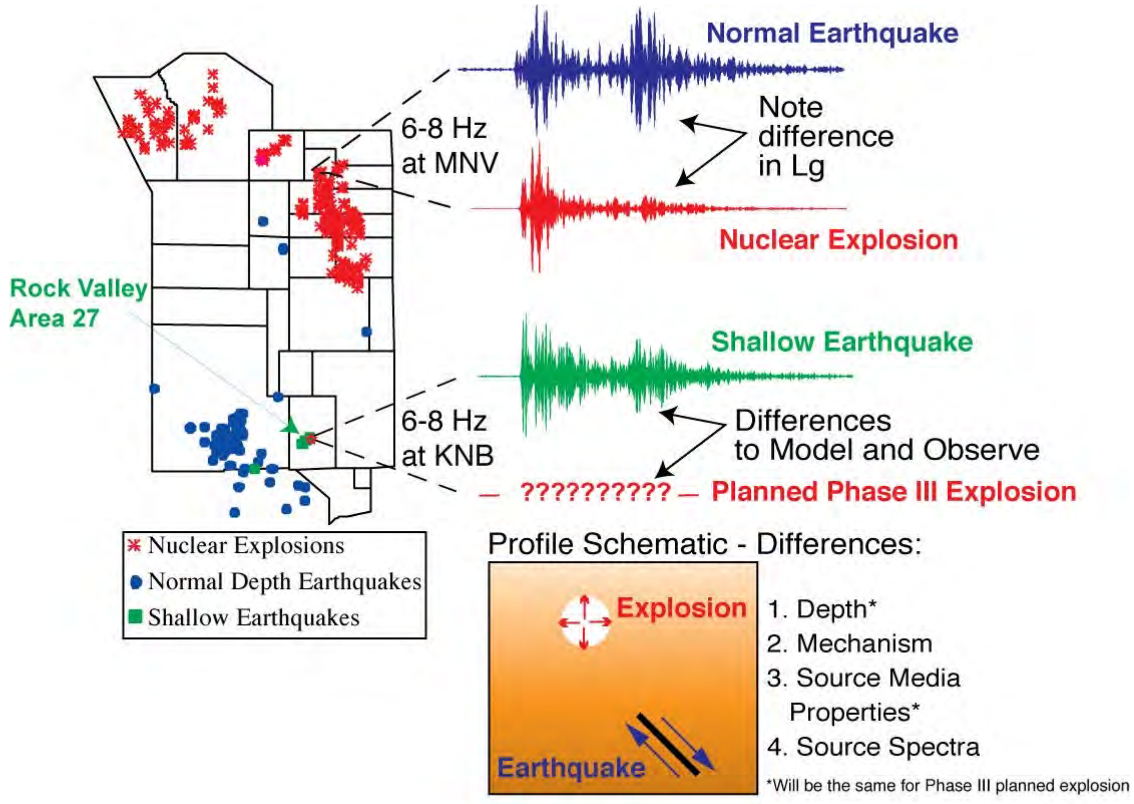
- Nuclear Explosion Monitoring focuses on discriminating seismic sources and estimating yields.
- Wave propagation effects complicate seismic signal and make discriminating small sources challenging.



https://www-gs.llnl.gov/nuclear-threat-reduction/nuclear-explosion-monitoring

Natural Laboratories

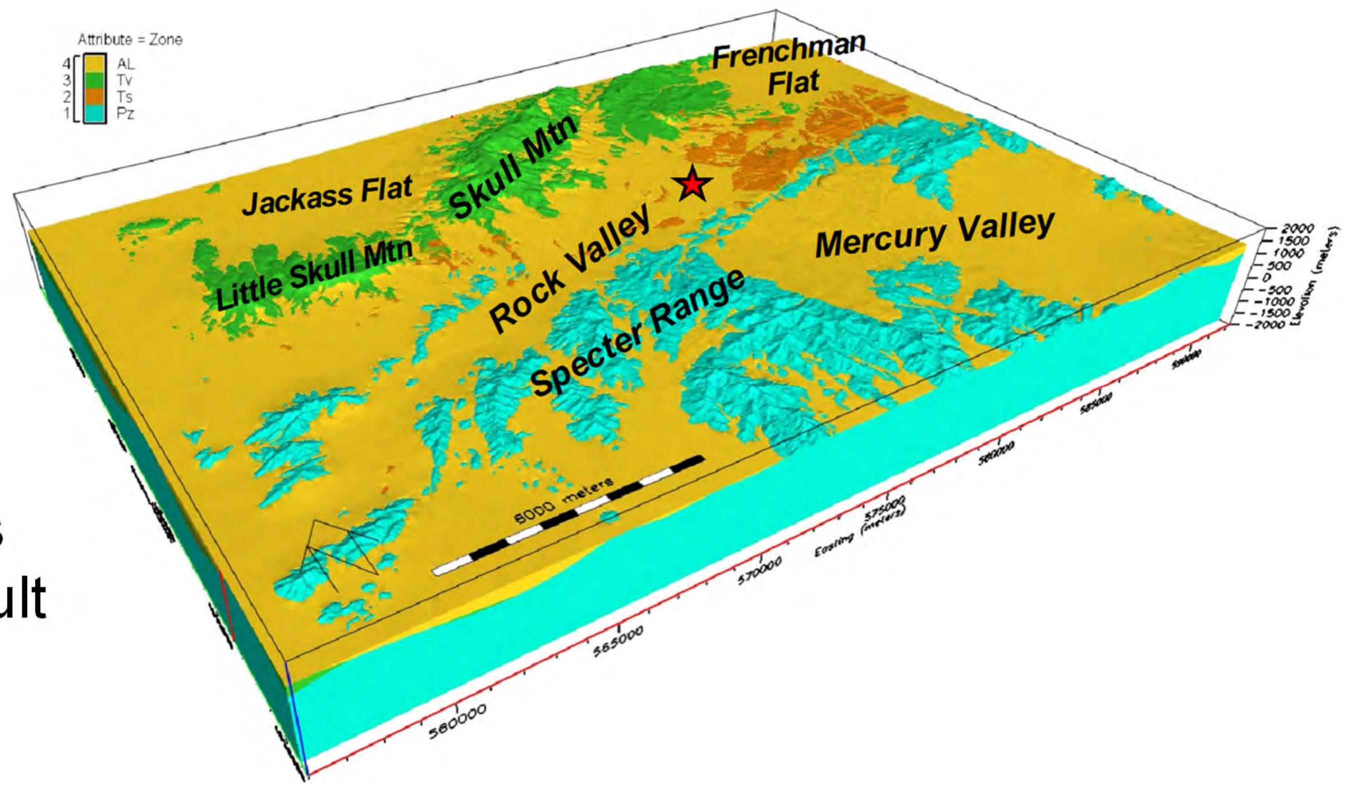
- The 1993 earthquake sequence in the Rock Valley Fault Zone produced exceptionally shallow seismicity
- Opportunity to directly compare earthquake and explosive sources in the exact emplacement conditions



Map of nuclear tests (*red*), normal depth earthquakes (*blue*), and unusually shallow earthquakes (*green*) at NNSS (Snelson et al. 2019)

Objectives

- Refine earthquake locations
  - Minimize depth uncertainty
  - Prepare testbed
- Inform and refine geologic model
  - Earthquake locations image subsurface fault structure



Rock Valley Geologic Framework Model (GFM)

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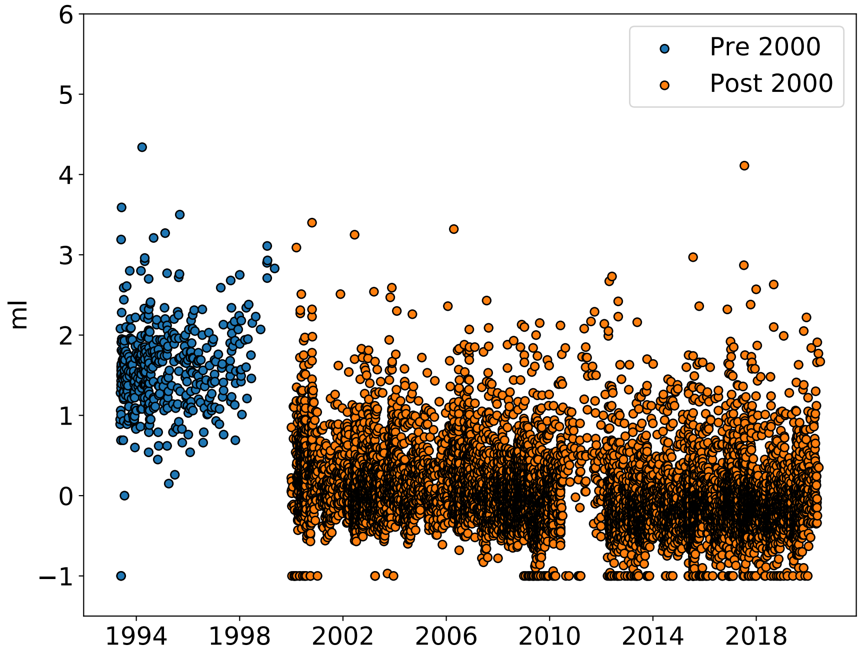
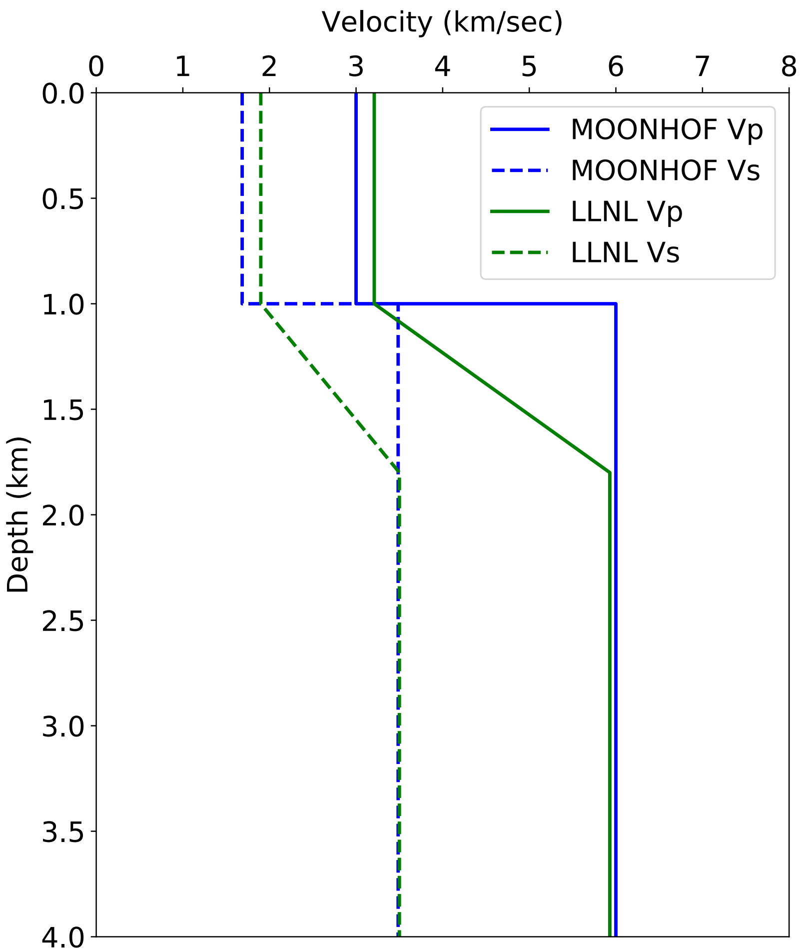
Rock Valley Seismicity and Velocity Characterization

- Rock Valley well recorded on NSL seismic network
- Analog network prior to 2000
- Regional velocity models



Rock Valley earthquake catalog. Blue indicates converted analog data and orange indicates digital data.



NNSS velocity models LLNL and MOONHOF from Anderson and Myers (2010) and Hoffman and Mooney (1983)

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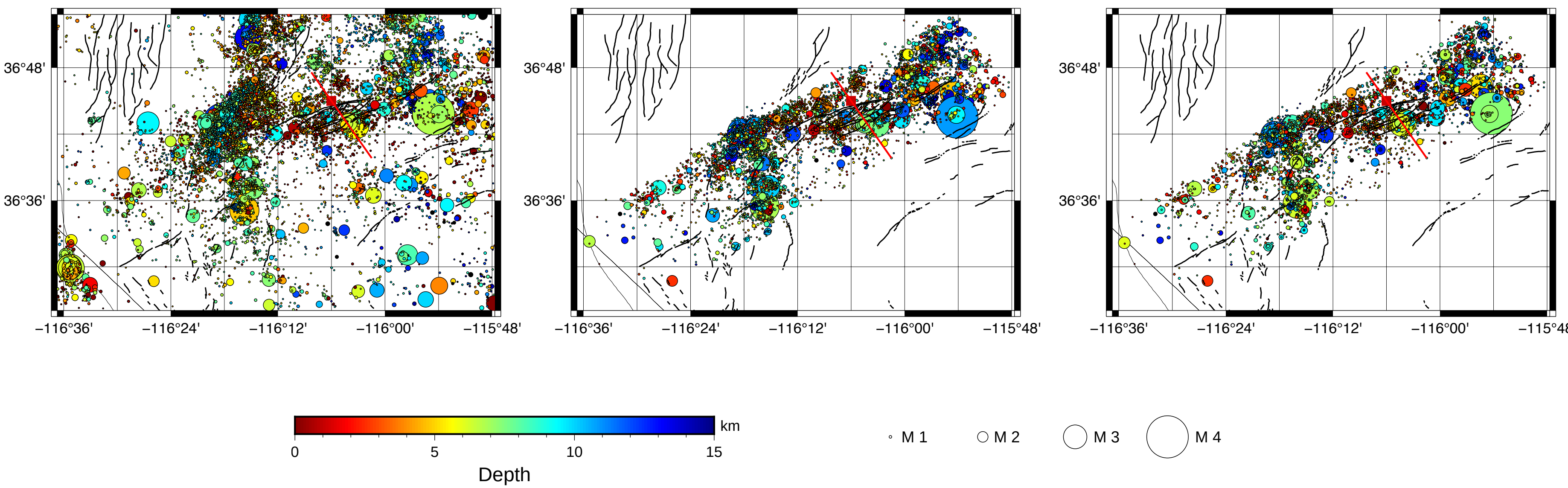
Relocation Methods

Catalog → Absolute Relocation: Hypoinverse → Relative Relocation: GrowClust



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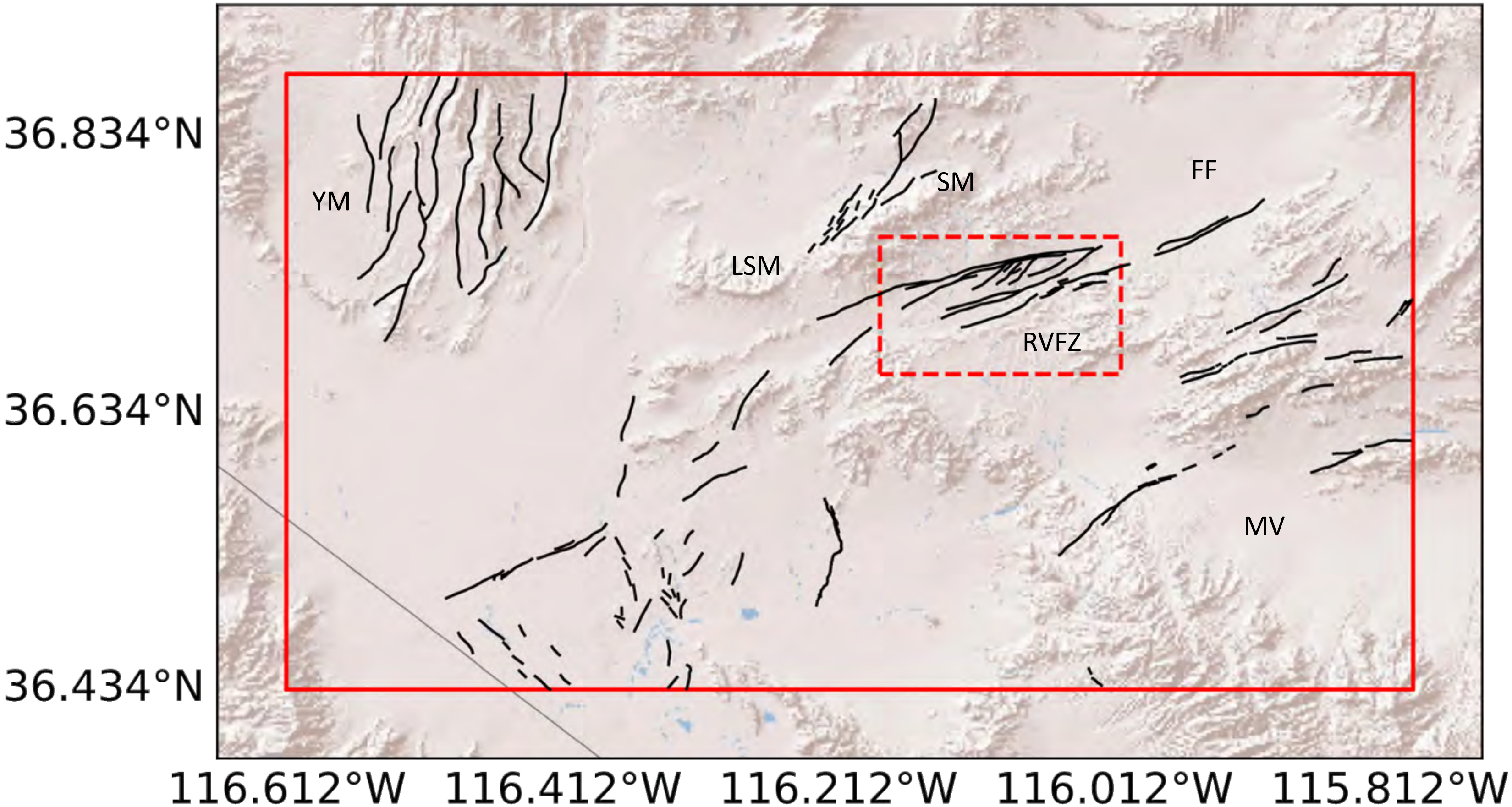
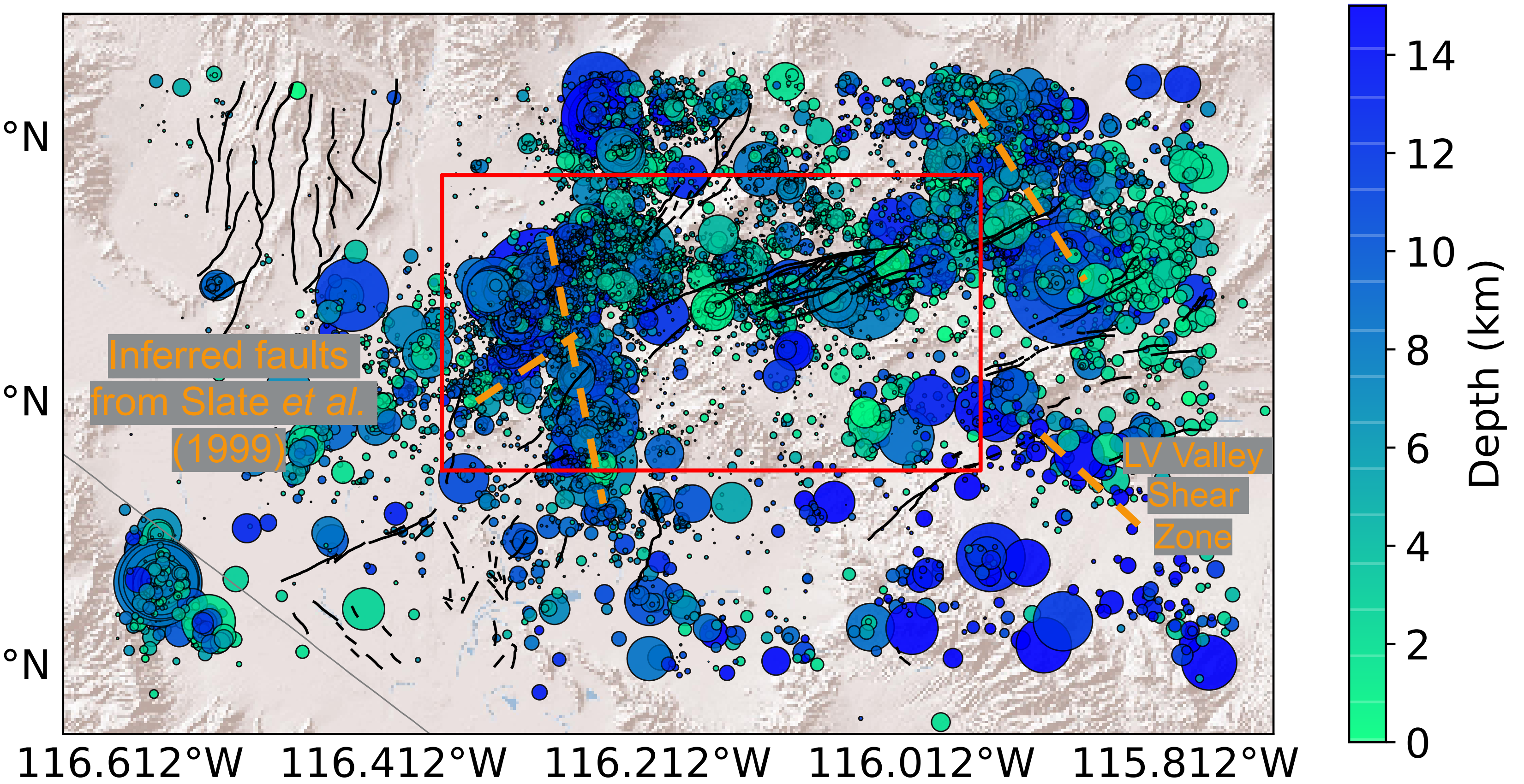
Relocation Domains

- Relocate large domain and small domain to test the effect of lateral velocity heterogeneity on relocation accuracy and quality



Hypoinverse Results



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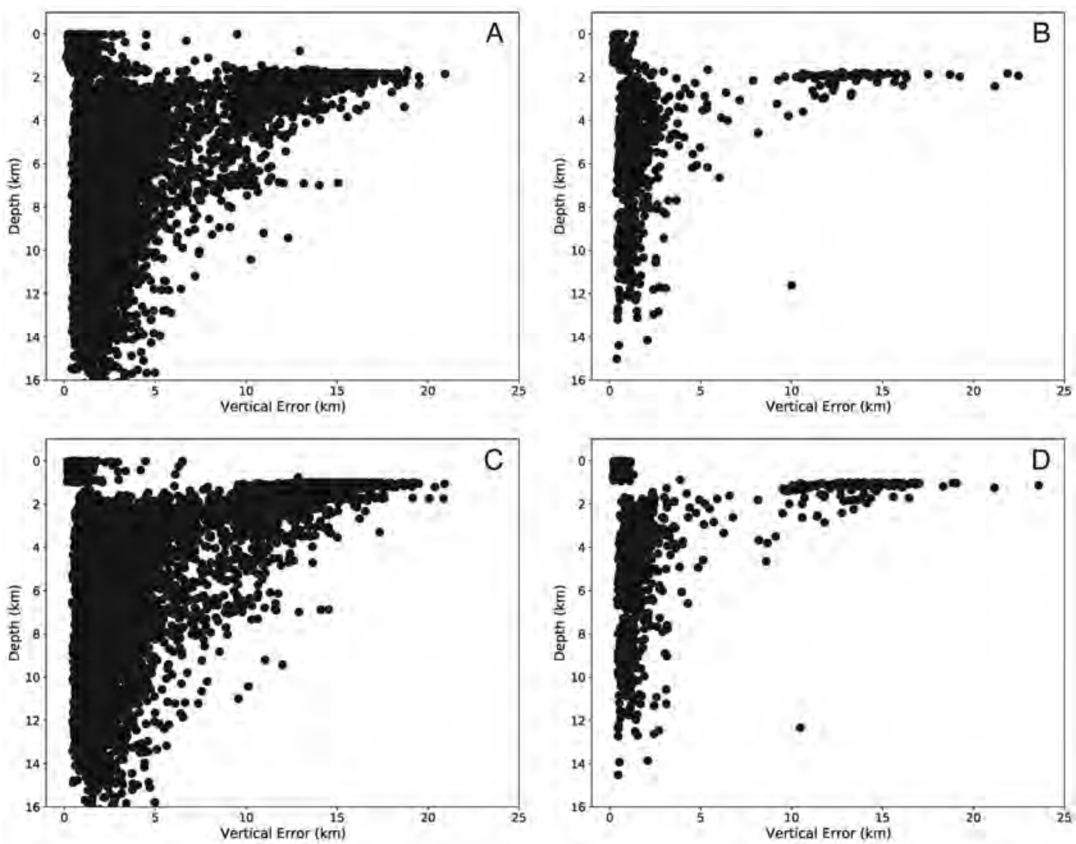
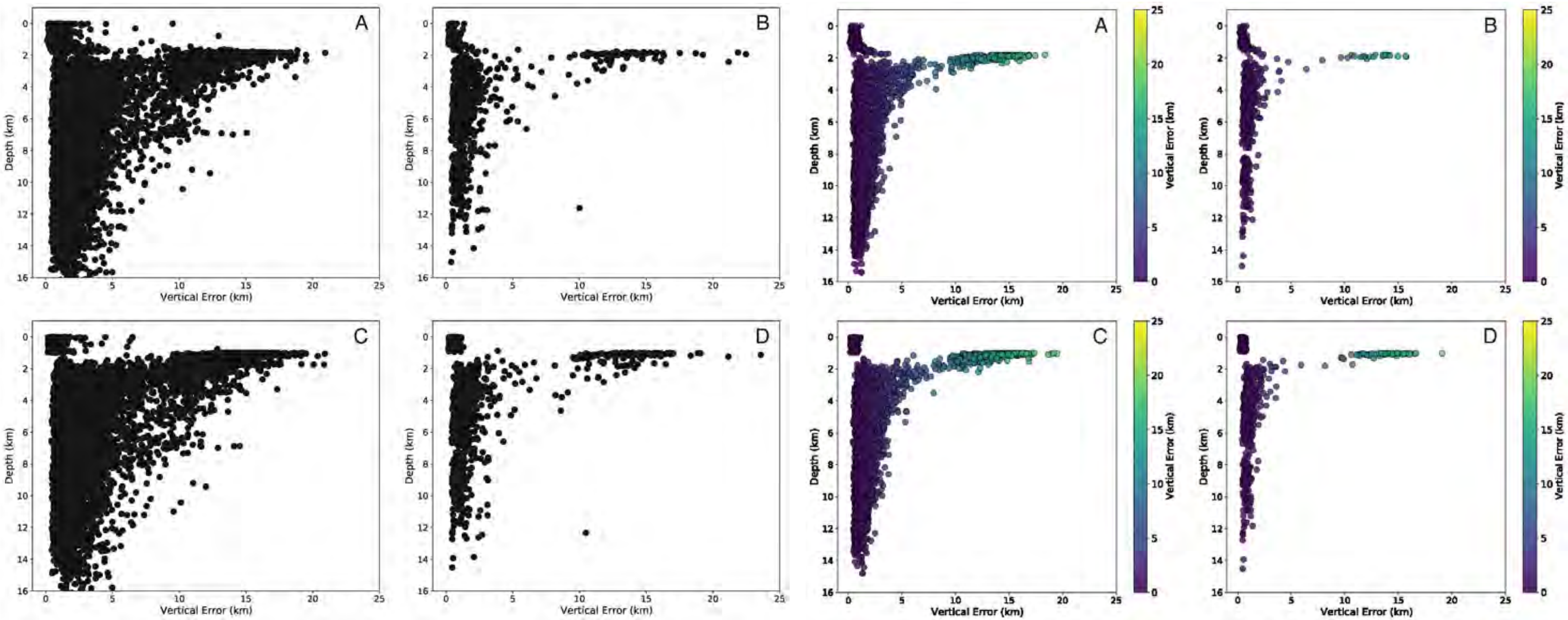
Location Accuracy



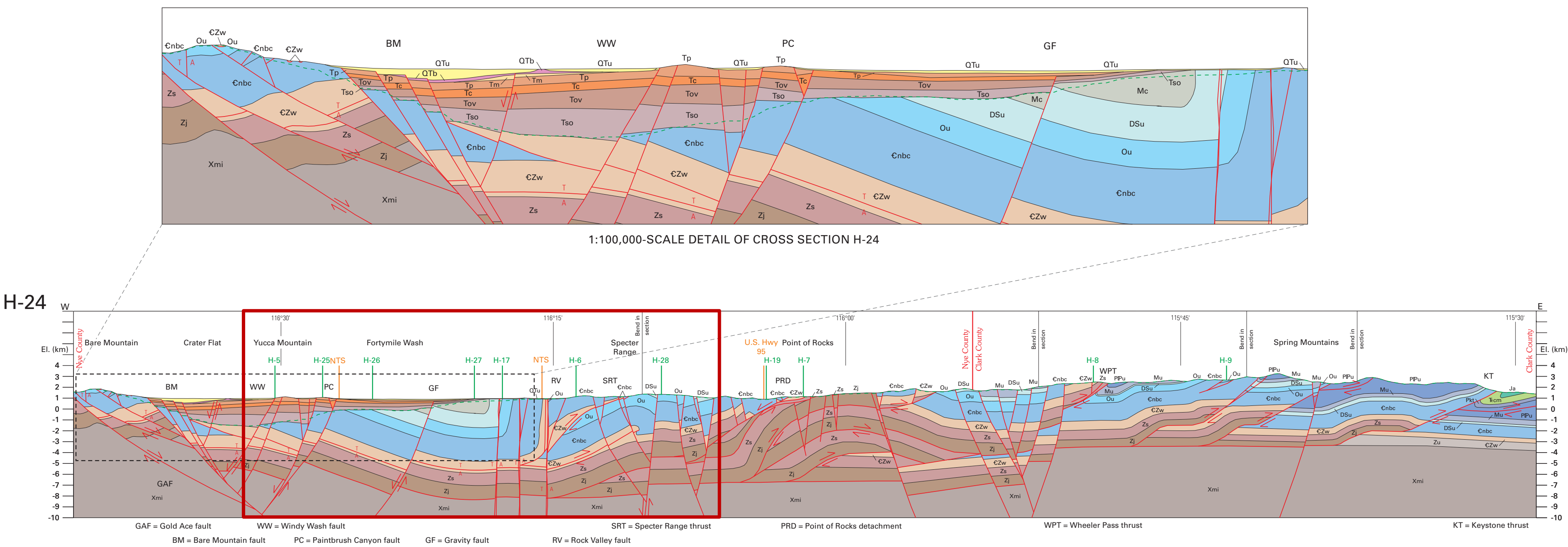
- Sharp increase in vertical error at 1.5–2.0 km regardless of velocity model
- Error decreases with depth as lateral heterogeneity decreases
- Is this a characteristic of data quality?
  - At least 10 phases
  - Minimum of 5 S phases
  - Station within 15 km
  - Maximum azimuthal gap of 180°

Optimized Location Accuracy



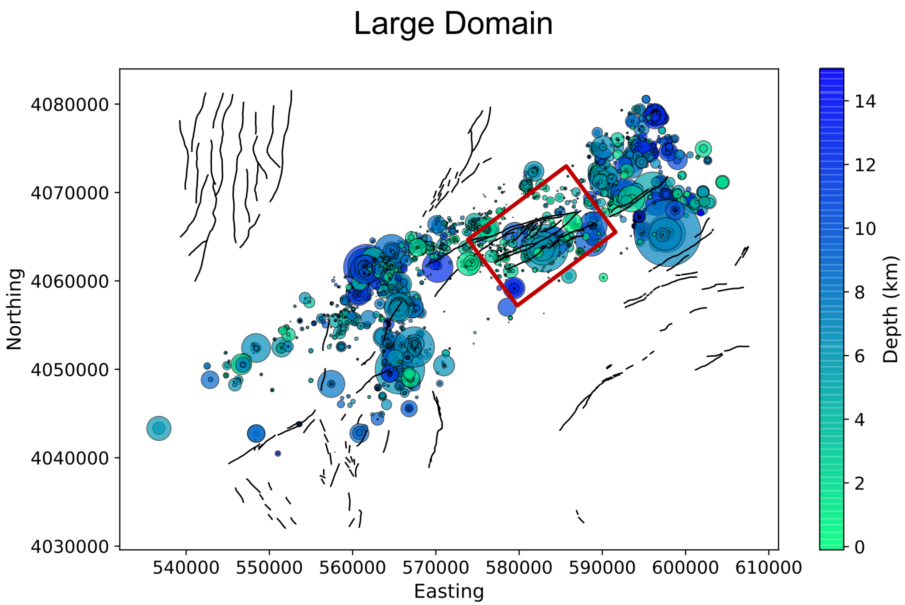
Geologic Investigations

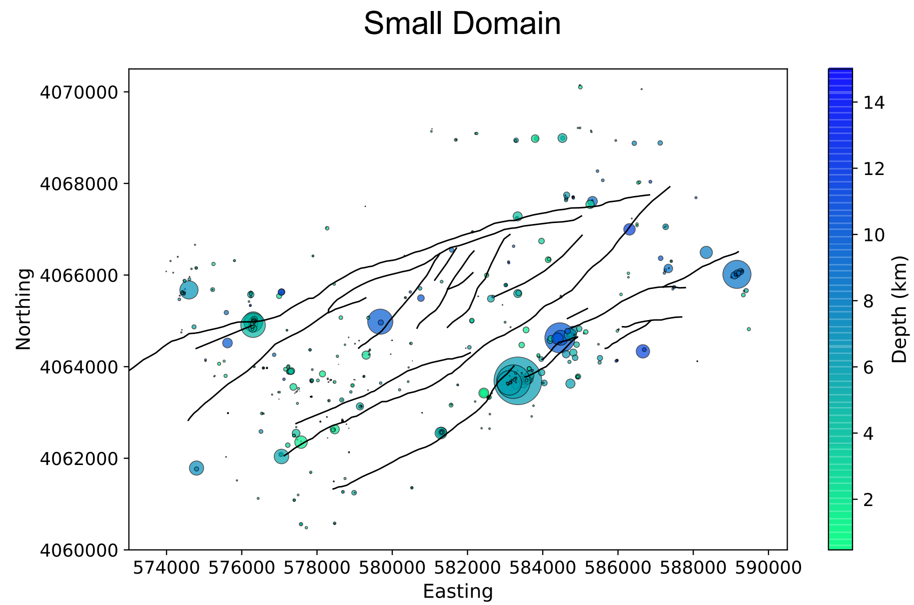
- The Rock Valley Fault Zone and the NNSS are located in a structurally complex region
- Lateral heterogeneity greatest toward surface



GrowClust Results

- Relative relocations highlight faults in the RVFZ

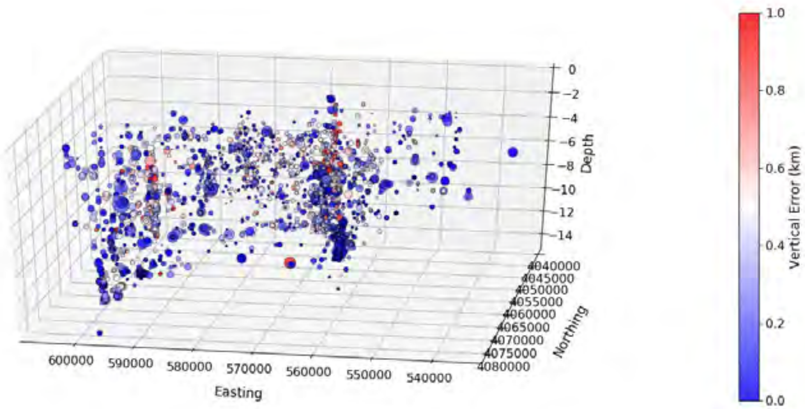


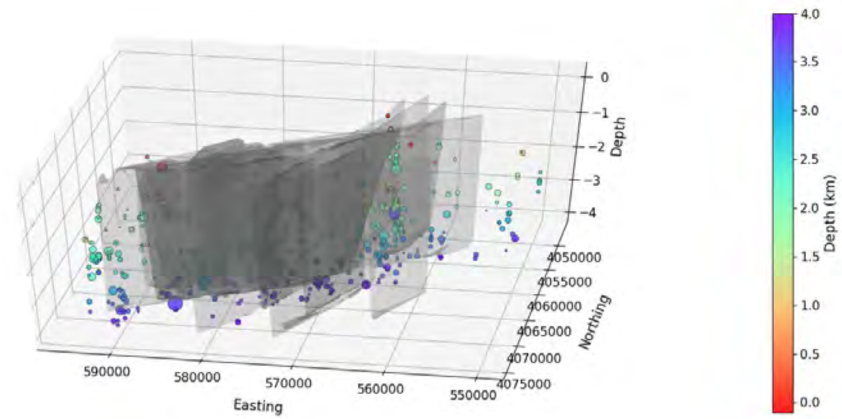


GrowClust Results

- GrowClust location accuracy:
  - Mean vertical error: 0.18 km
  - Median vertical error: 0.096 km

- Relocated earthquakes correlate with mapped faults
- Relocated events will be used to refine subsurface projection of mapped faults





Conclusions

- Events can be located within a 1.09 km and 0.5 km median vertical and horizontal error
- Sharp increase in the error between 1.5 and 2.0 km indicates the regional 1D velocity models are insufficient at locating events in the shallow crust
- After investigating quality control parameters, we concluded 1D velocity models are insufficient at locating shallow events and 3D velocity models are necessary to refine the location for the RVDC
- Provides insight into the subsurface structure
- Relative relocations prove to be robust over large regions

Future Work

- Investigate the feasibility of 3D relocation to minimize location uncertainty
- Integrate relocations into GFM to refine fault geometry