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Constraining Geologic Structure of the Rock Valley Fault Zone: Dense Gravity Analysis for the Rock Valley Direct Comparison Experiment

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Introduction – EQs vs. Explosions

- Direct comparisons of earthquake and explosion seismic wave propagation through geologic structure are sparse. Rock Valley (RV), Nevada provides a testbed where a chemical explosion will be compared to co-located shallow earthquakes (Figure 1).
- 3-D geologic framework models (GFM) provide the foundations for evaluating seismic-wave propagation signals and simulations (Figure 2).

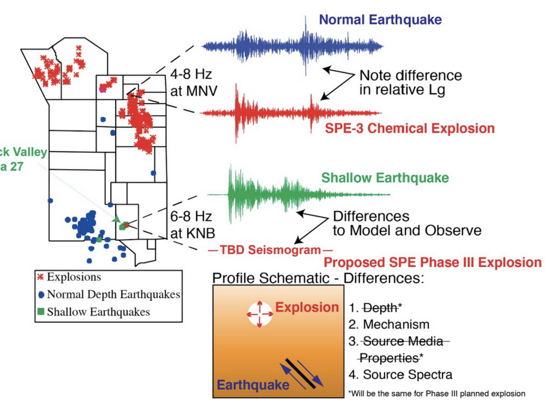


Figure 1: Earthquake vs. chemical explosions of SPE III. (right)

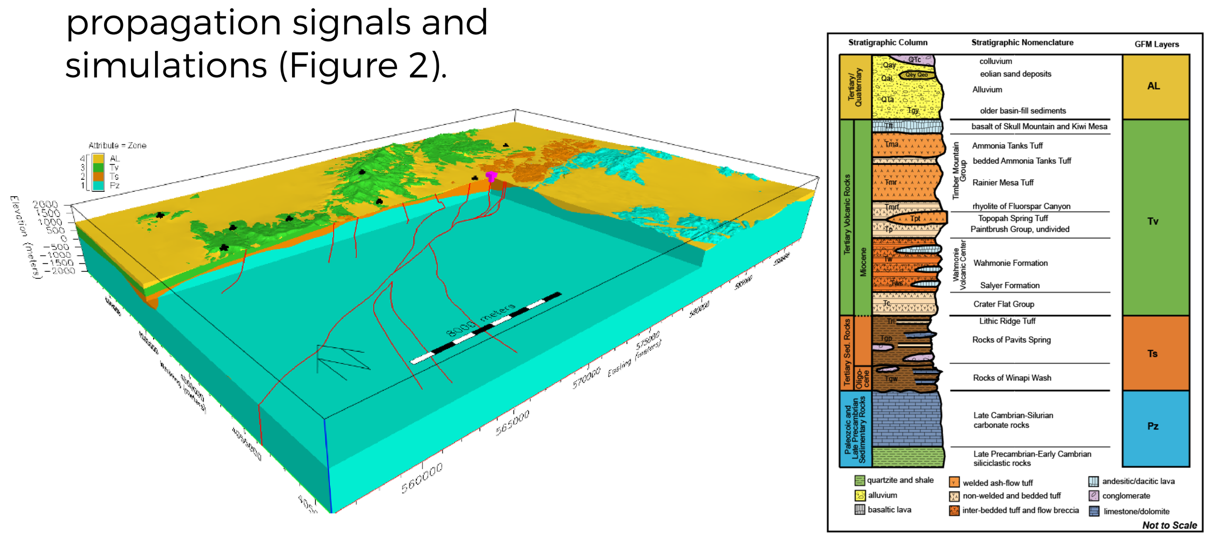


Figure 2: (left) Example GFM of the RV study area. (right) Description of geologic units in the study area. From Prothro, (2020).

- We present results from a high-resolution gravity survey in RV. This gravity dataset is being combined with recent P and S seismic tomography in a joint geophysical inversion. This work informs GFM development by constraining the underlying geologic and fault structure

Study Area – Rock Valley Fault Zone

- The Rock Valley fault zone (RVFZ; Figure 3) is an east-northeast zone of mostly left-lateral strike-slip faulting in the southern Nevada National Security Site (NNSS) (Prothro, 2020).
- Tertiary sedimentary rocks are characteristic in the southern region of the RVFZ with thick alluvial deposits and sparse volcanic rocks in the northern area Figure 2).
- A 1993 shallow earthquake swarm (yellow stars) in RVFZ provides seismic data which can be compared to an upcoming chemical explosion source.

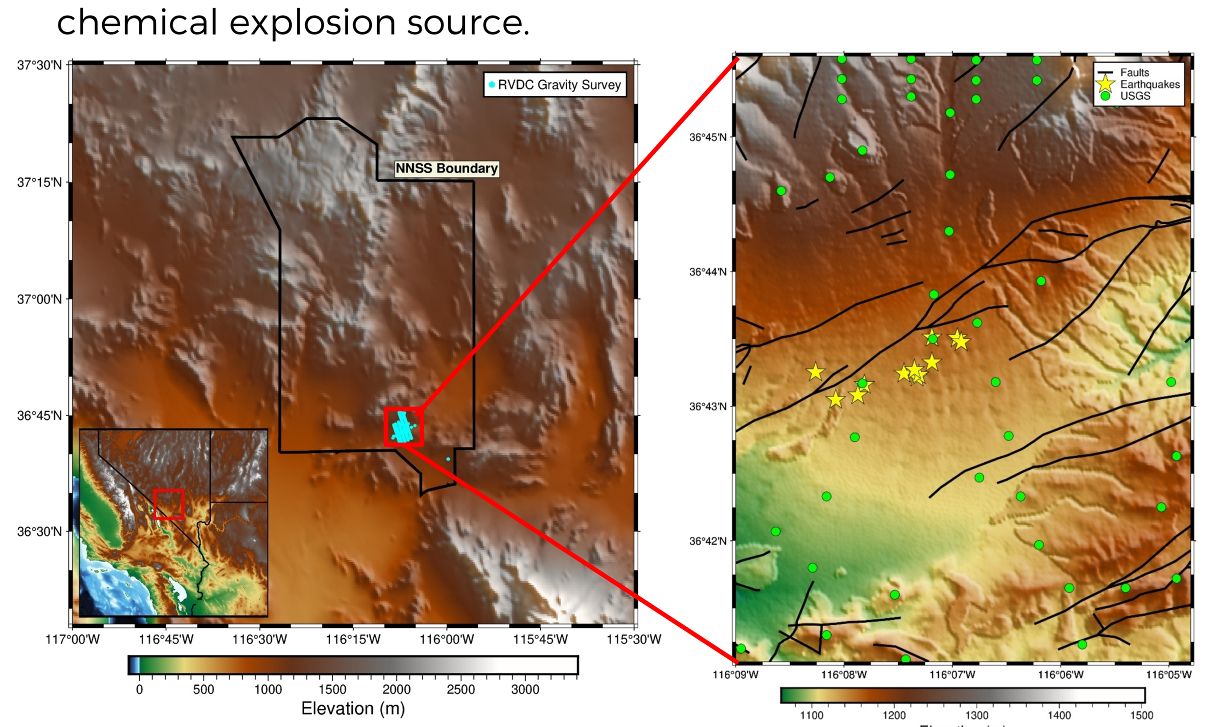


Figure 3: Map of southern Nevada with NNSS boundary. Blowout shows gravity survey with RVFZ faults. Stars indicate the 1993 shallow earthquake swarm. Sparse USGS gravity measurements are shown as green dots. From Walter et al.,(2012)

- Regional gravity data is sparse in RVFZ (Figure 3). Our dense gravity acquisition provides a high resolution dataset to evaluated fault and basin structure, and to further constrain local seismic models.

Rock Valley – Gravity Survey

- Sandia collected 212 gravity points in the RVFZ on April 25th 2022 to May 4th 2022 (Figure 4).

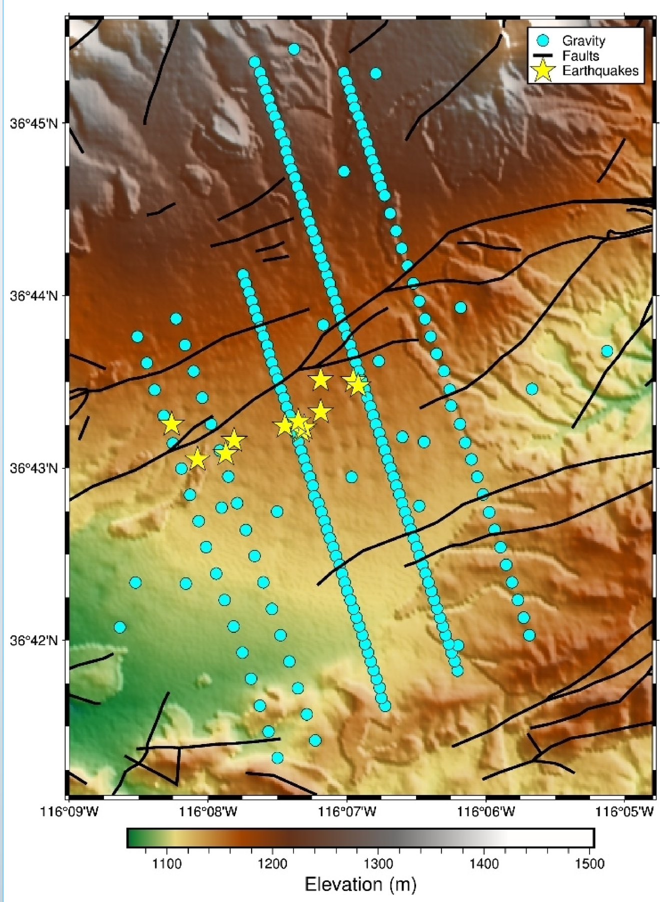
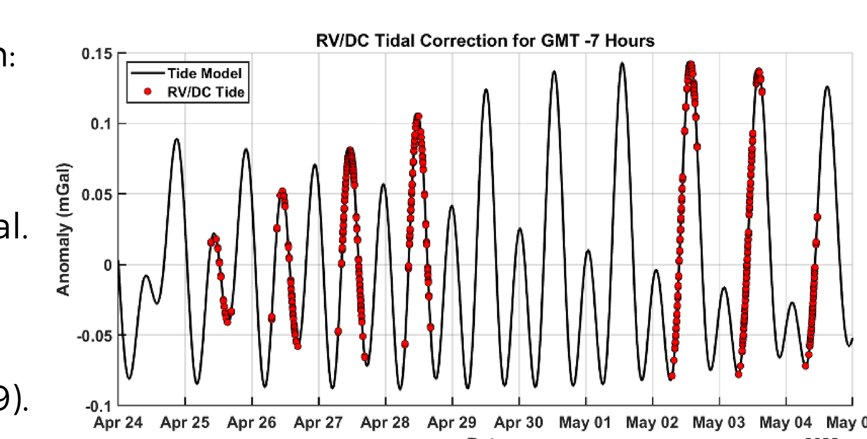


Figure 4: Map of gravity survey conducted in the RVFZ.

- A base station in Mercury 13 km from the array ties the gravity measurements to regional data.
- Reoccupied 12 USGS stations.
- 5 gravity lines (Figure 4) with 200-700 m line separation and 100-200 m point separation.
- Gravity lines perpendicular to RVFZ faults.
- Spans the 1993 shallow earthquake swarm (stars), and future explosive test.
- Gravity points precisely located by GPS prior to measurement.

Gravity Corrections – Tidal and Instrument Drift

- Tide correction: Applied Ltide Matlab functions of Bjelotomić et al. (2019) that derive the formulas of Longman (1959).
- Instrument drift: Determined from a linear least-square fit on repeated station measurements at the base station.



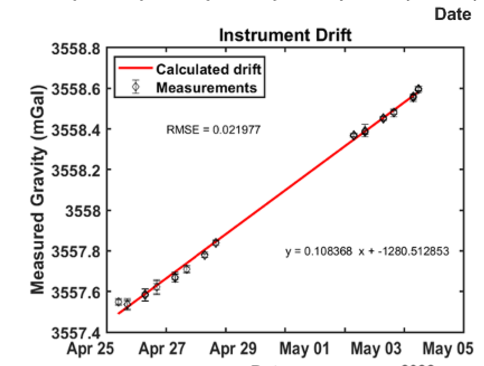


Figure 5: (top) Predicted gravity tidal correction. (right) Predicted instrument drift through time with base station measurements.

Gravity Disturbance

- Gravity disturbance (δg_D) accounts for gravity at a height above the ellipsoid (Hofmann-Wellenhof and Moritz, 2006).
- In the region of interest (Red Box; Figure 6):
  - High elevations in the north (~1300 m) have a 2 mGal correction.
  - Low elevations in the valley (~1100 m) have a -25 mGal correction.

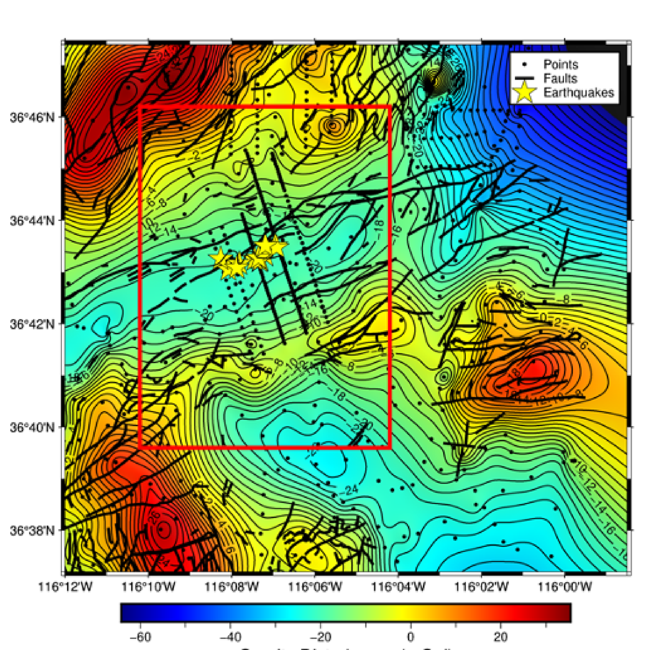


Figure 6: Gravity disturbance elevation reduction.

Bouguer Disturbance

- Gravity disturbance (δg_D), Bouguer (δg_B), and terrain (δg_T) corrections are applied to the normal gravity (γ). We calculate the Bouguer anomaly from measured gravity (g_p) using:

$$\Delta g = g_p - (\gamma - \delta g_D + \delta g_B - \delta g_T)$$

- Final map uses the dense survey and regional USGS data.

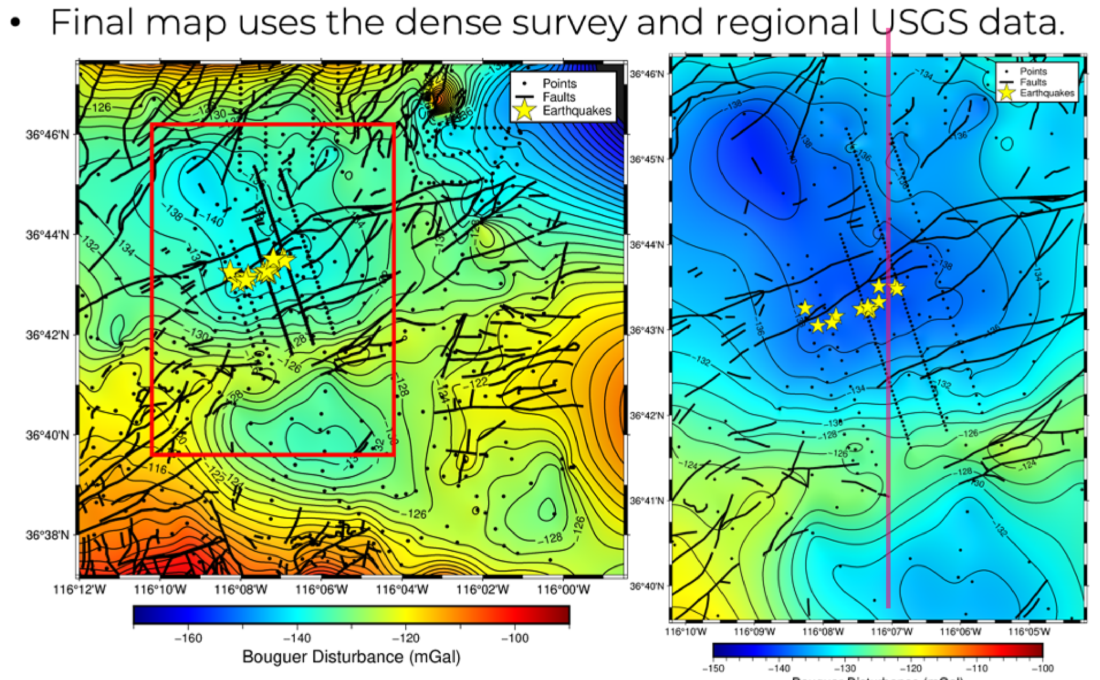


Figure 7: Bouguer disturbance map obtained by applying all the necessary corrections

- In the region of interest (red box; Figure 7):
  - Gravity lows ~-142 mGal near the onset of Tertiary volcanics (Skull Mountain).
  - Gravity highs ~-120 mGal SW near Specter Range.
  - In the fault zone, ~-138 mGal increasing east & west of the 1993 sequence.
  - Saddle structure in the south with a secondary gravity low northeast of the specter range.

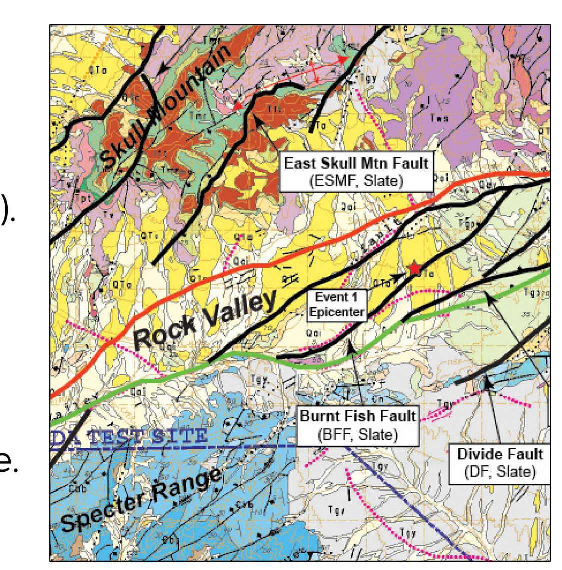


Figure 8: Geologic map of the RVFZ region. Red star is largest 1993 event.

Gravity Corrections – Bouguer and Terrain

- Bouguer (δg_B) and terrain corrections (δg_T) account for the material above the ellipsoid and the effect of nearby terrain respectively. Harmonica Python library (Uieda et al., 2022).
- Bouguer correction of -109 mGal northern RVFZ, -121 mGal in valley (Figure 9).
- Forward modeled topography as prisms with density of 2670 kg/m^3 for effect of terrain on the gravitational field.
- Terrain effect in northern region of RVFZ 113 mGal with flattest valley topography 95 mGal (Figure 9).

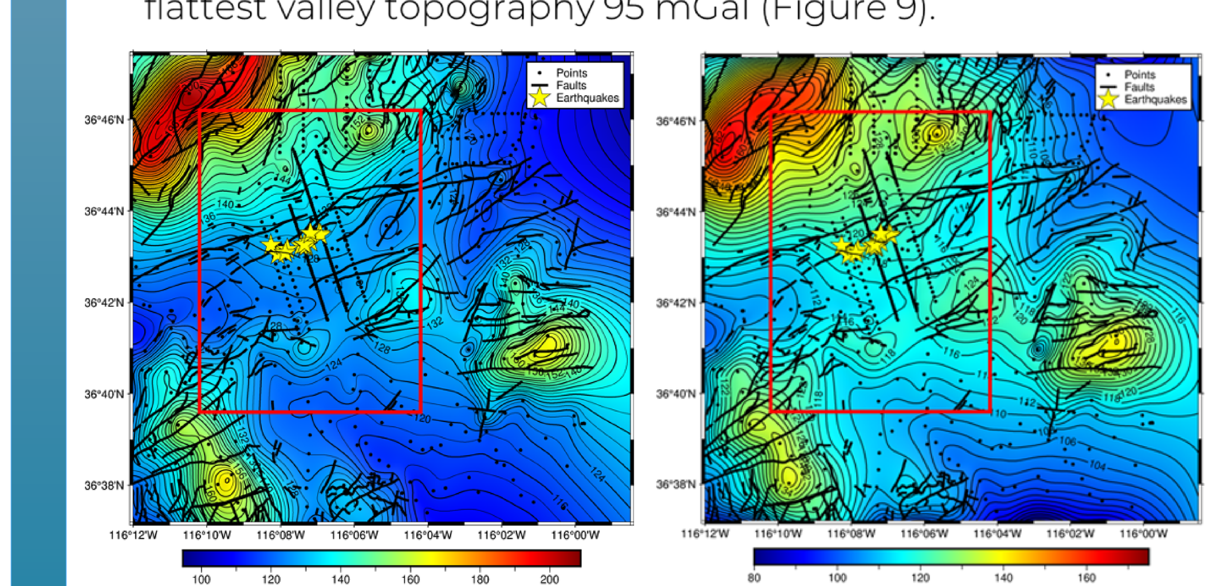


Figure 9: (left) Map of Bouguer correction. (right) Map of terrain effect.

Discussion

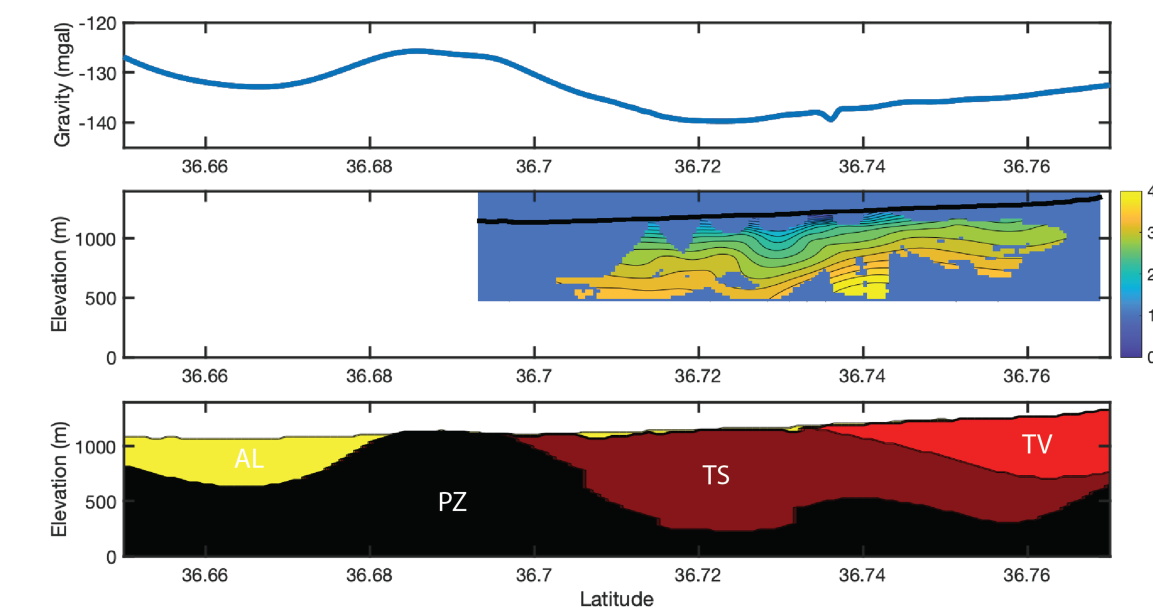
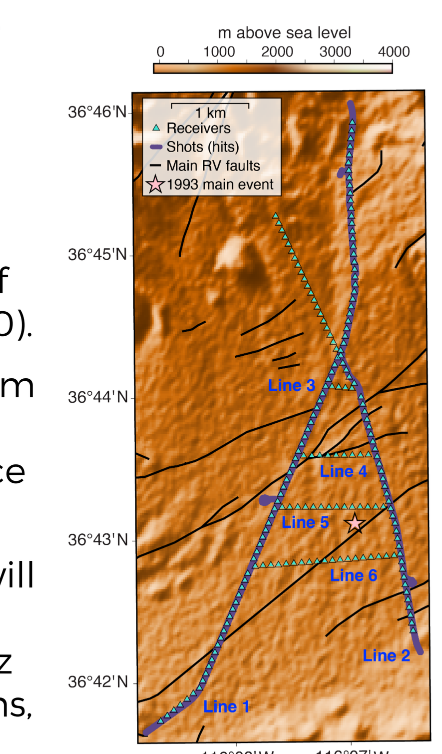


Figure 10: Cross sections at Longitude = -116.12 (Pink line Figure 7). (top) Bouguer Gravity anomaly. (middle) Velocity model (Vp) Harding et. al, 2023. (bottom) current GFM.

- Gravity anomaly correlates well with the Paleozoic sedimentary rock basement captured in the GFM. Tertiary Volcanics to the north appear to have a positive influence, offsetting the deepening PZ.
- Gravity lows neat the 1993 sequence correlate with a low velocity zone around the RV faults.
- Individual faults are not obvious in the gravity map or velocity models alone. Joint inversion of these datasets may illuminate subtle features.

Towards a Joint Seismic-Gravity Inversion

- Los Alamos National Laboratories collecting 5 additional gravity lines.
- Jointly inverting dense relative gravity measurements with seismic data enhances the upper 1 km resolution of the velocity model (Preston et al., 2020).
- Active source seismic P and S data from accelerated weight drop (Figure 10, 11; Harding et al., 2023). Additional, surface wave data may be available.
- Combining gravity and seismic data will help constrain the shallow RVFZ structure. Uses include constraining Pz basement, refinement of fault locations, and helping define future drilling.



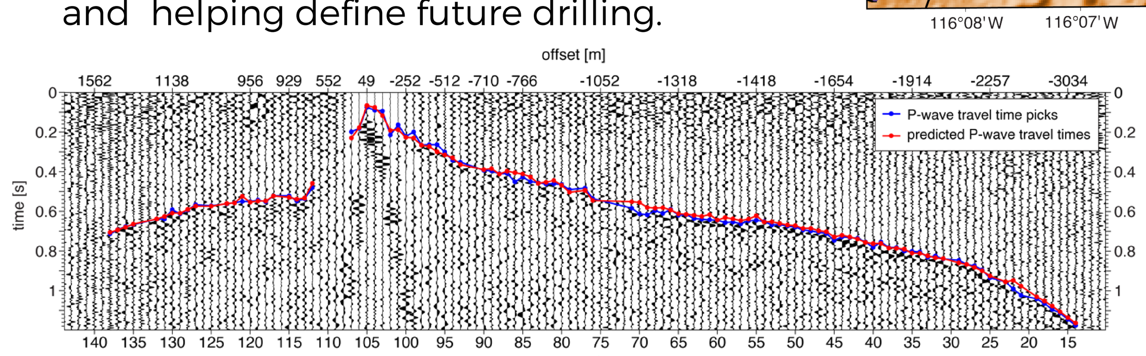


Figure 11: (top) Map of the AWD survey. Green symbols are seismic stations, blue symbols are AWD shot locations. From Harding et al., (2023). (bottom) Example of AWD P data including analyst picks and predicted travel times.

References & Financial Statement

- For PDF of references scan the QR code.
- SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.