The California Geological Survey Response to the 20 December 2022 magnitude M6.4 Ferndale Earthquake Sequence

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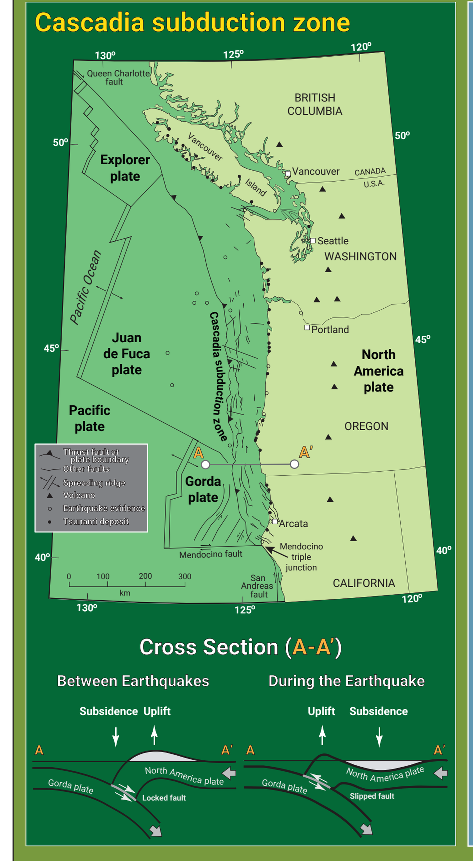
Seismic hazard in coastal northern California (CA) has an annualized earthquake loss of over $30 million USD. While the two largest contributors to seismic hazard in CA are the San Andreas and Cascadia subduction zone fault systems, Gorda intraplate earthquakes are the largest source of annual seismicity in CA. In the Mendocino triple junction (MTJ) region, these two overlapping fault systems interact in ways that we are only beginning to understand. Based on seismicity, the 20 December 2022 magnitude M6.4 earthquake ruptured 40-50 km of a N70E striking intraplate fault zone within the subducted Gorda plate.

Understanding the potential impact from future earthquakes supports community preparedness and mitigation to protect lives and reduce potential damage to infrastructure. An essential part for estimating hazards from future earthquakes is the documentation of ground deformation following earthquakes to better develop relations between earthquake source parameters and the occurrence of surface effects caused by shaking and surface rupture.

The California Geological Survey (CGS) and U.S. Geological Survey (USGS) operate an earthquake field response program designed to collect field observations of fragile and perishable geologic evidence for earthquakes that impact the state. The CGS, with Federal, State, and non-profit partners, coordinates earthquake field investigations through the CA Earthquake Clearinghouse (CEQCH). The CEQCH activated a virtual clearinghouse following the M6.4 earthquake to support coordination and documentation of multi-agency field observations.

The CGS and the USGS have been collaborating closely since the 2019 Ridgecrest Earthquake to develop a data acquisition schema to collect ephemeral data and to create a field data acquisition system which can be deployed within 15 minutes for post-earthquake investigations. Field observations include landslides and cracks in sand dunes and road fill, though there was no evidence for liquefaction.

Cascadia subduction zone



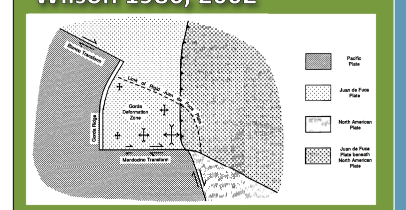
The Cascadia subduction zone is a convergent plate boundary where the oceanic Explorer, Juan de Fuca, and Gorda plates subduct beneath the continental North America plate. Where these plates meet is the Cascadia megathrust fault.

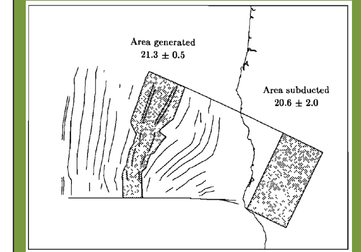
The earthquake cycle produces different types of deformation during different parts of the earthquake cycle (lower panel). Megathrust earthquakes generate strong ground shaking, trigger landslides, induce liquefaction, and generate local and trans-pacific tsunami.

The 20 December 2022 M6.4 Ferndale Earthquake Sequence was not an interface earthquake on the megathrust, but was an intraplate earthquake within the Gorda plate.

Gorda Plate Structure

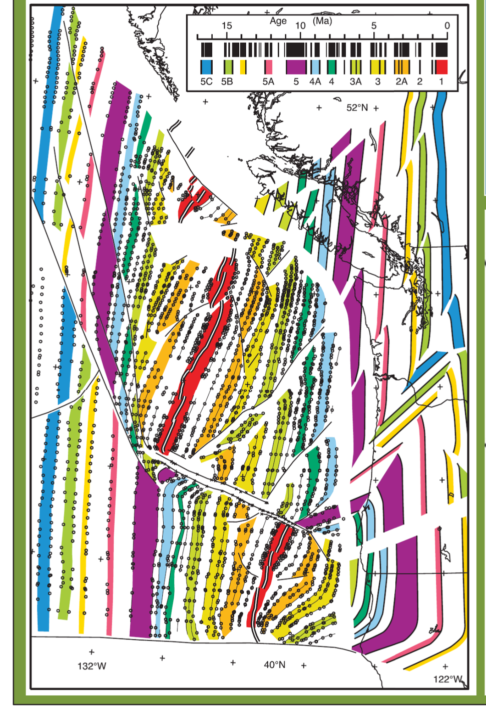
Wilson 1986, 2002



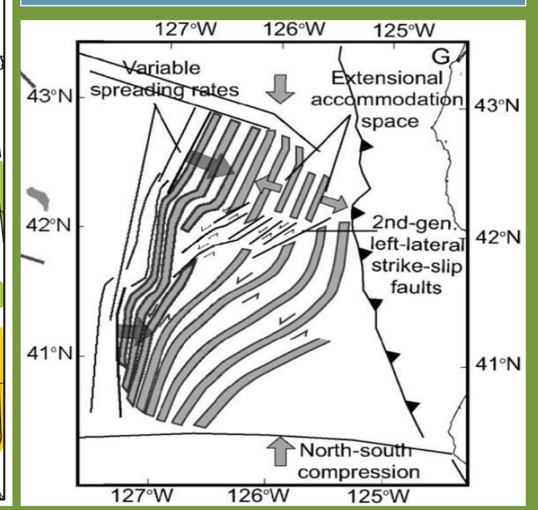


Cartoon of proposed tectonic model for the Gorda deformation zone (Wilson, 1986). Schematic strain symbols show direction and relative magnitude of extension (outward arrows) and compression (inward arrows).

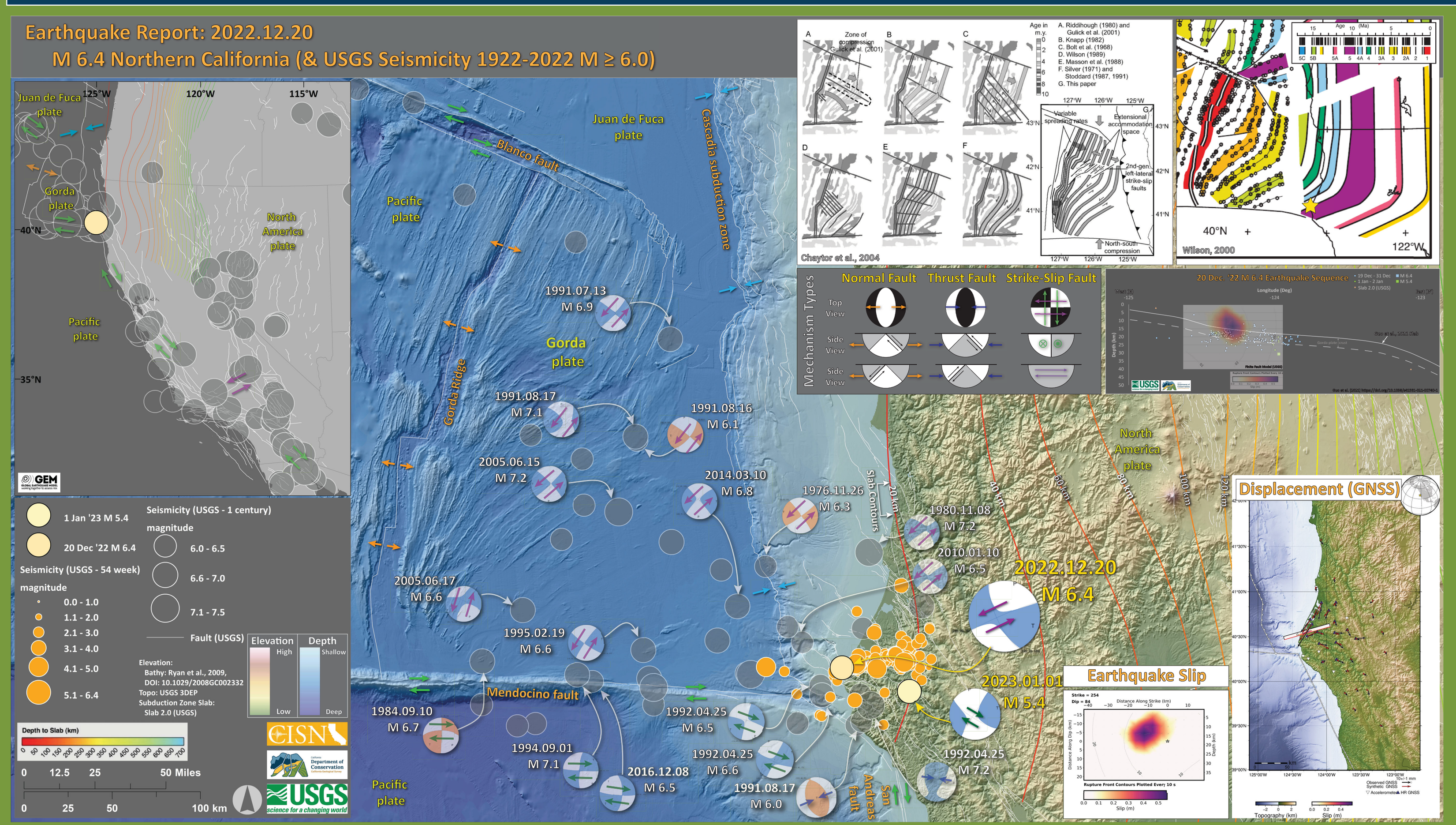
Wilson (1986) used a kinematic model based on Gorda isochrons to construct a tectonic history of the Gorda plate over the past 5 Ma. Wilson compares the plate surface area generated since 1.77 Ma and compares this with the area that has been subducted to suggest that the plate has undergone compression over this time period (plate area is not conserved).



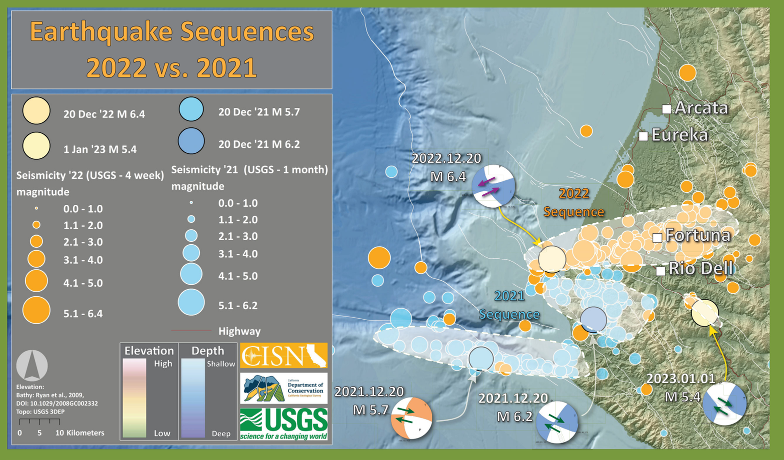
Left: Seafloor age map, modified from Wilson (2002).
Right: Tectonic deformation interpreted by Chaytor et al. (2004).



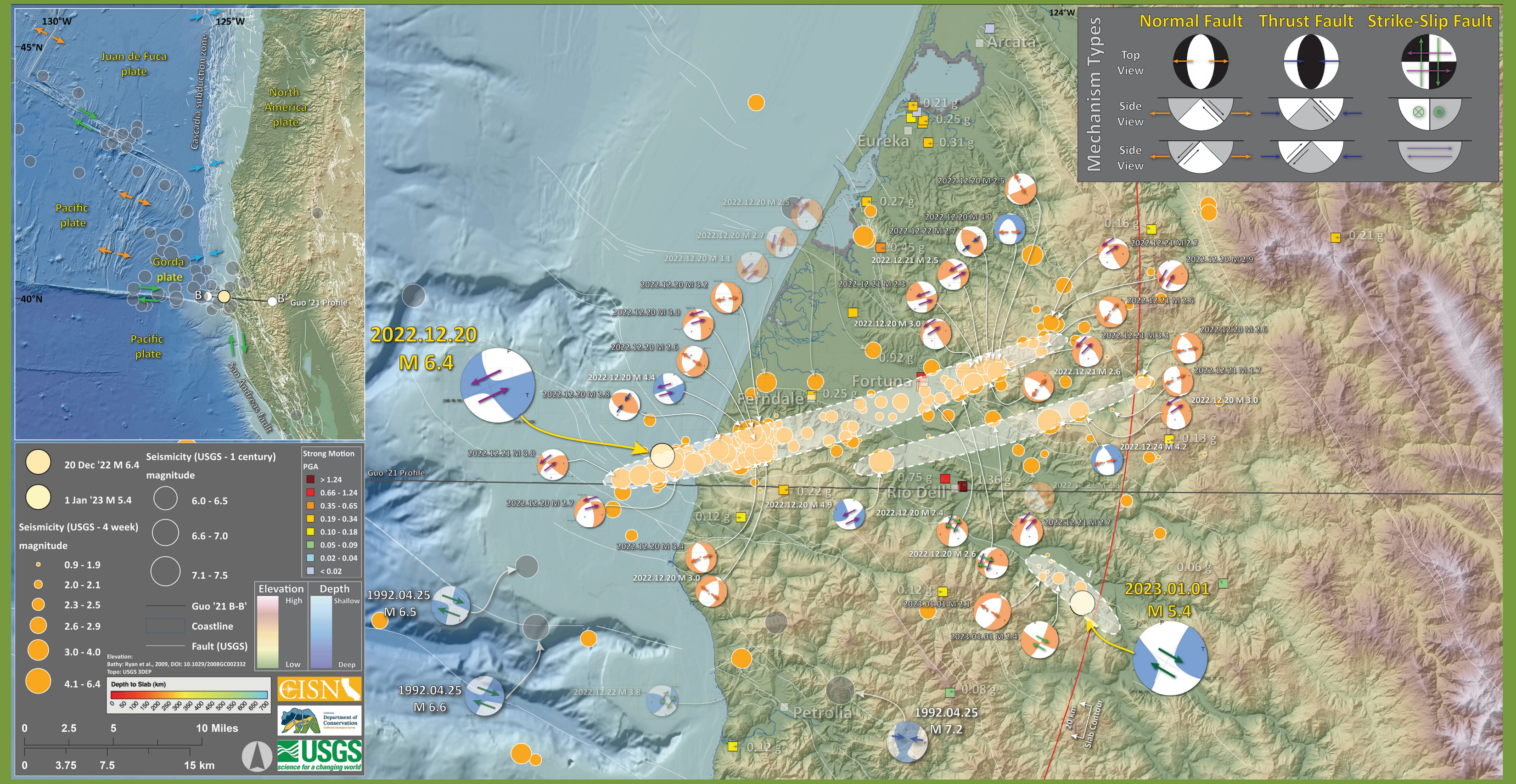
Ferndale Earthquake Sequence



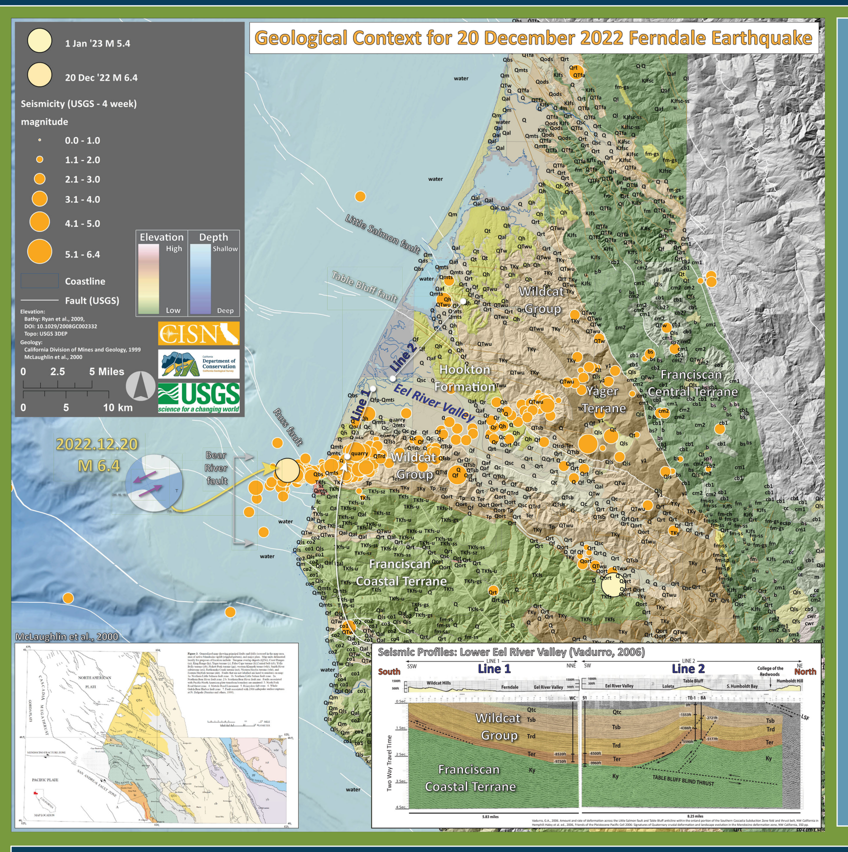
The Gorda plate forms at the Gorda Ridge, an oceanic spreading center, where normal (extensional) faults form parallel to the ridge.
In southern Gorda, in the Mendocino deformation zone (aka the Triangle of Doom), as the plate is shortened from compression north to south, these faults rotate in a clockwise fashion and are reactivated as left-lateral strike-slip faults as evidenced by the mechanisms from these historic earthquakes.
In the upper right are figures from Chaytor and Wilson. Chaytor et al. (2004) presented a comprehensive review of hypotheses about why these faults have rotated. Wilson (2002) shows the magnetic anomaly isochrons as interpreted from marine geomagnetic data. Wilson also presents what these isochrons may look like in the subducted parts of the plates. Note the location of the M6.4 epicenter as shown by a yellow star.
On the center right we see earthquake hypocenters (the depths) plotted along a profile of the Gorda plate from Guo et al., 2021, projected along this black line B-B' in the map below.



Coincidentally there was an earthquake sequence that happened on 20 December 2021. The 2021 event had two events with overlapping seismic waves which made it challenging to interpret. We eventually learned that there were two main events, each with a distinct aftershock region. The '21 M 6.2 was also a Gorda plate event and the M 5.7 was related to the Mendocino fault.



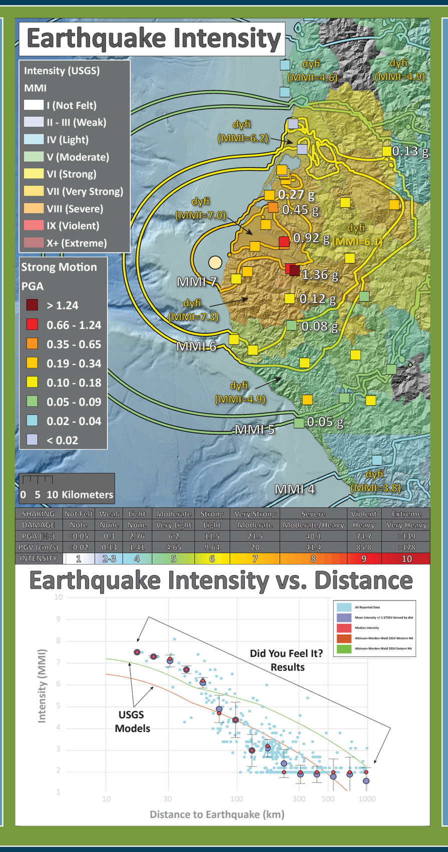
Here are the earthquake mechanisms from most of the earthquakes in this sequence.
These mechanisms are predominantly left-lateral strike-slip and normal (or extensional) earthquakes. There is one compressional or thrust event. There are some right-lateral strike-slip events associated with the M 5.4 triggered earthquake.
Also plotted are the CSMIP ground acceleration data in Peak Ground Acceleration (PGA, g).
Hypothetical fault locations are outlined in white. The main northeast trending fault is consistent with the magnetic anomalies and the orientation of faults in the Mendocino deformation zone. The northwest striking M5.4 is consistent with seismicity trends from historical earthquakes (e.g., 1992 Cape Mendocino, see M6.5 & M6.6 mechanisms).
See the Hamid Haddadi poster presentation on Wednesday, "Strong-Motion Records of the M6.4 Ferndale Earthquake on 20 December 2022 and Its Aftershocks."



Here is a brief view of the surface geology in the region, using California Division of Mines & Geology (1999), now called the California Geological Survey, and McLaughlin et al. (2000) mapping.

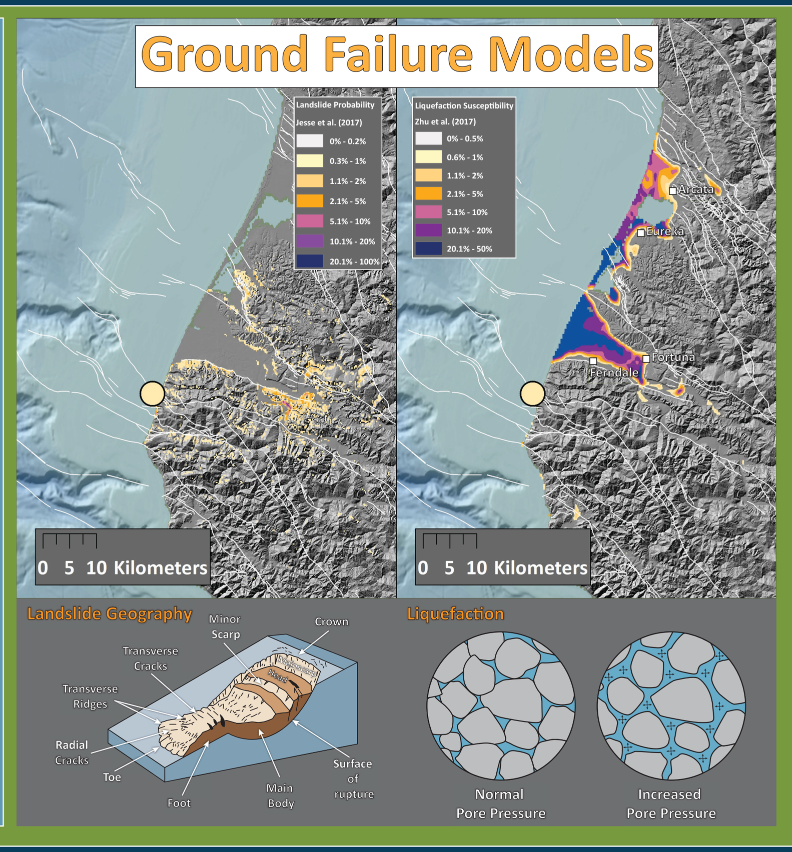
Note 3 things:
(1) The Neogene to Quaternary (3 Ma and younger) Eel River sedimentary basin rocks (Wildcat Group) are folded downwards in a syncline. May have contributed to shaking.
(2) The latest Quaternary to modern Eel River fluvial system is inset within this older sedimentary basin. May have contributed to shaking.
(3) The M 6.4 seismicity trend runs oblique to the surface geology.

If there was slip into the NAP and this was along a fault that does this repeatedly, perhaps there would be geologic evidence for this at the surface (?).



Here is a comparison between the modeled intensity and the reported intensity. Both data use the same color scale, the Modified Mercalli Intensity Scale (MMI). The colors and contours on the map are results from the USGS modeled intensity. The Did You Feel It? (DYFI) data are plotted as a transparent colored overlay and represent observations made by people using the DYFI part of the USGS website.

In the lower panel is a plot showing MMI intensity relative to distance from the earthquake. The models are represented by the green and orange lines. The DYFI data are plotted as light blue dots. The mean and median are plotted as orange/purple dots. Note the deviation of the DYFI data compared to the modeled data. Why do you think this is?



To the left are two maps that show the potential for earthquake triggered landslides (left, Jesse et al., 2017) and earthquake induced liquefaction (right, Zhu et al., 2017).

These are USGS data products. The USGS prepares these products that can help people identify places to investigate for geological evidence of these phenomena.

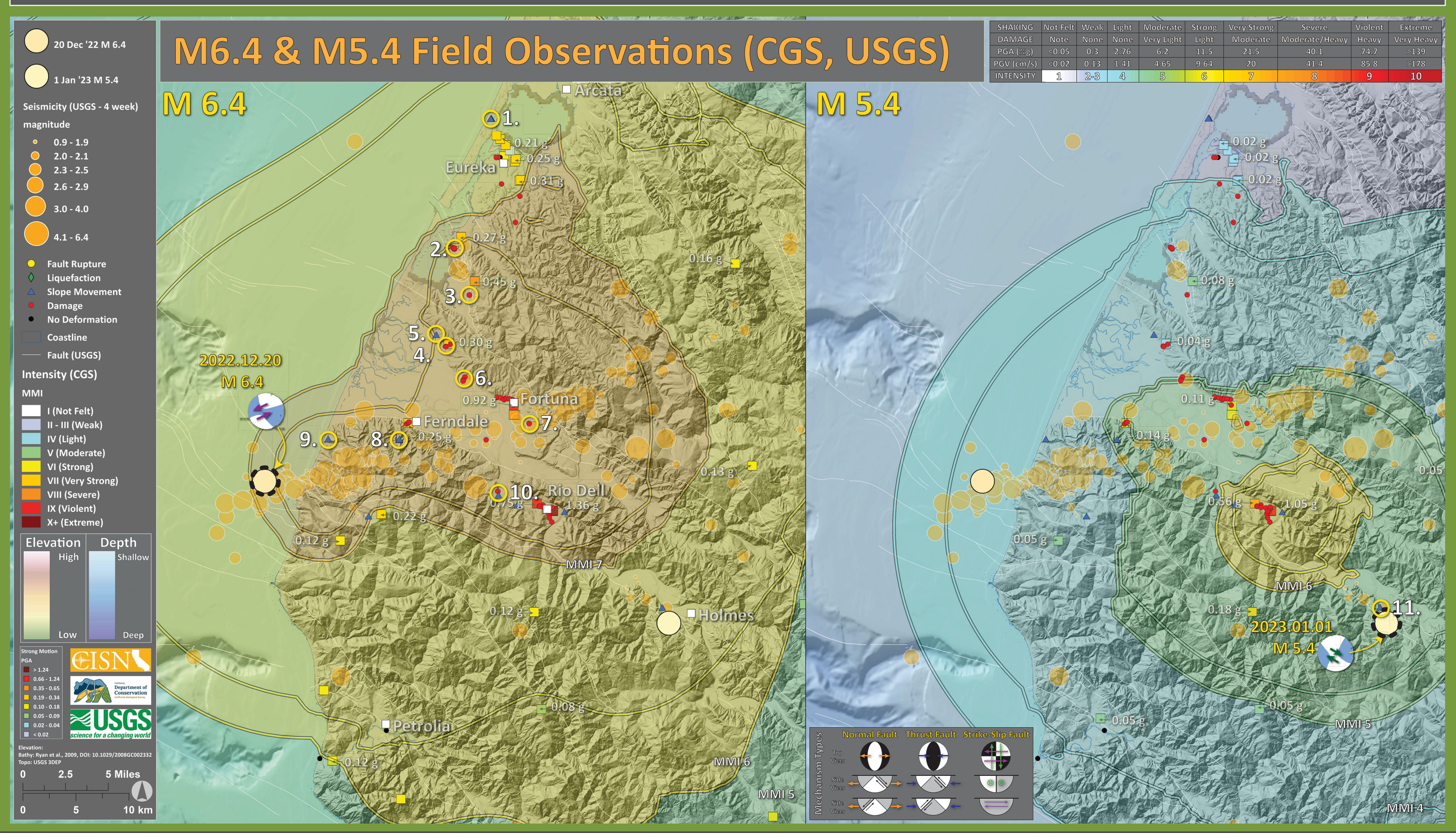
Event Response

The California Geological Survey responds to a variety of natural hazard events including volcanic eruptions, landslides, post-fire events, earthquakes, and tsunami. Most of these efforts are closely coordinated with our response partners from other organizations.
Each appropriate unit runs their specific response which includes a variety of information gathering methods. These information gathering methods include the activation of field teams that collect observations of perishable features. For example, during the 2019 Ridgecrest Earthquake Sequence, dozens of CGS geologists collaborated with USGS and academic geologists to document evidence for surface rupture from the M 6.4 and M 7.1 earthquakes.
The USGS and the CGS collaborated to develop a mobile data collection application that can be used on mobile devices using the ESRI Field Maps app. Field personel use this "schema" to enter observation data into the GIS database. This data collection application can be activated as a blank database, for each natural hazard event, in as little as 15 minutes using a python script designed by Luke Blair (SUSG) and Kate Thomas (CGS).
See the session 208B Kate Thomas oral presentation on Thursday, "Post-Earthquake Response Application: A New and Improved Method for Data Collection Using Arcgis Field Maps."

Within a few minutes of the earthquake, Pridmore, Patton, and Dawson collaborated to prepare an "Earthquake Quick Report" that was delivered to the California Governor's Office of Emergency Services so that their office are informed about the size, location, etc. of the earthquake.

At 8:00am, the CGS held a videoconference call to discuss the scope of an event response activity. CGS staff were identified who would make observations of fragile & perishable features that were geological evidence of the earthquake. Geologists stationed at the Eureka CGS Forest and Watersheds program office decided to collect these data. Within a few hours of this meeting, putting some of their personal needs aside (like broken dishes on the floor) they headed into the field. One geologist in the Tsunami Unit, who also lives locally, joined them for field work on the second day and utilized support from the Eureka National Weather Service office where there was backup electricity and internet access.

The CGS also coordinated their response with geologists from Cal Poly Humboldt Deprtment of Geology and the College of the Redwoods Earth Science Program. For the first time, CGS/USGS staff used social media information to enter data into the database. Read the list of contributors to this event response effort.

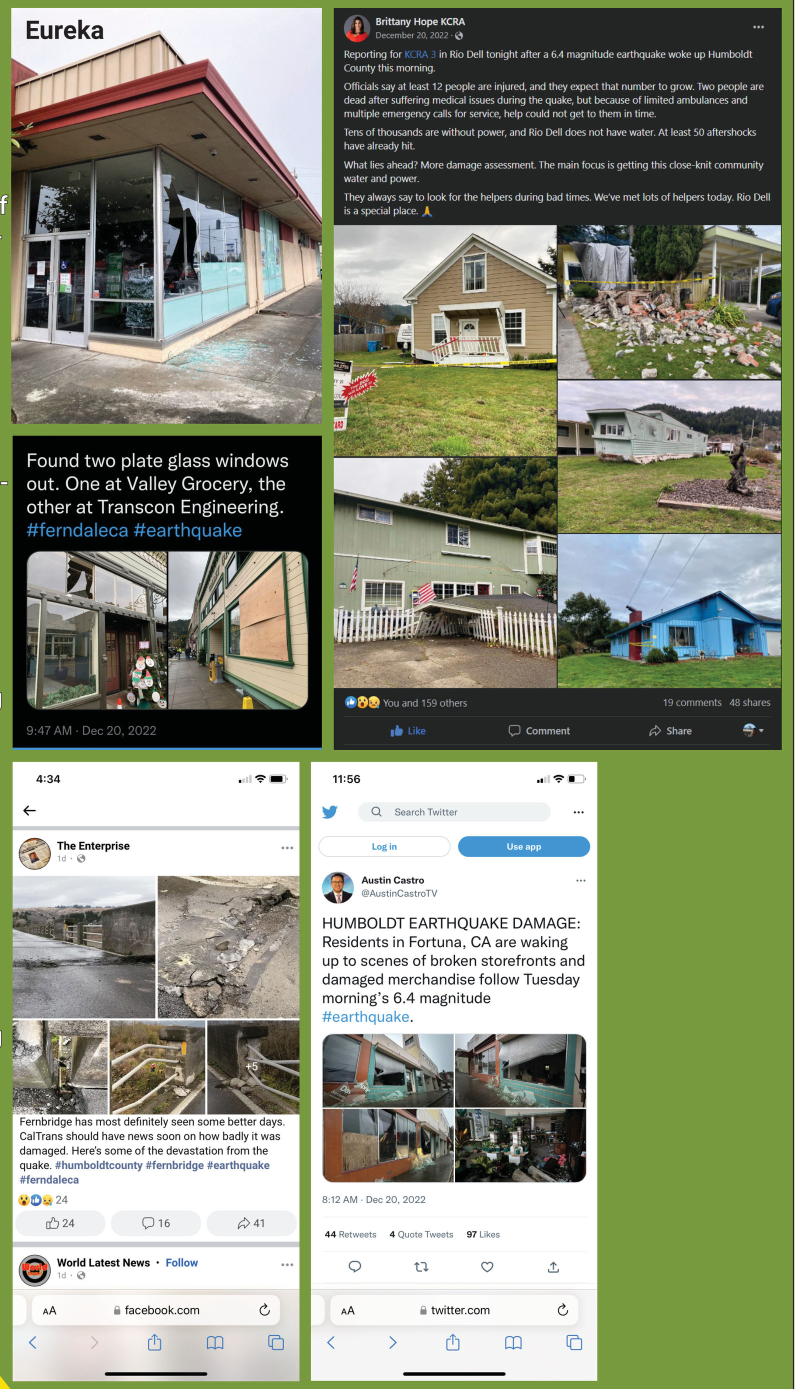


Field Observations

1. Landslide headscarps in sand dunes.
2. Road deformation along Thompkins Hill Road south of College of the Redwoods, adjacent to 2 high pressure natural gas lines.
3. Road cut slope failure approximately 10m wide.
4. Road deformation in Fields Landing.
5. Cracks along medial gravel bar, parallel to river flow direction.
6. Road cut bank slope failure along Table Bluff Road.
7. Road fill failure along Blue Slide Road.
8. Chimney failure in Rohnerville.
9. Reactivation of landslide above Centerville Beach.
10. M 5.4 Road cut slope failure along Avenue of the Giants near Holmes.
11. Structural collapse in Loleta.

Cal Poly Humboldt (CPH)
College of the Redwoods (CR)
California Strong Motion Instrument Program (CSMIP)
National Weather Service (NWS)

Social Media Observations



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