Revisiting an Enigma on California's North Coast: The M6.5 Fickle Hill Earthquake of 21 December 1954

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Conflict of Interest Statement

The authors declare no competing interests.

Key Points

1. The source fault of the 21 December 1954 M6.5 earthquake has remained a puzzle even after 70 years.
2. Seismic evidence and models suggest that the 1954 earthquake occurred on the Cascadia subduction interface.
3. Revisiting pre-digital earthquakes as in this study can increase our understanding of tectonics and hazard.

Abstract

Many earthquakes occur along the North Coast of California in the vicinity of the Mendocino Triple Junction (MTJ), where the Pacific, Gorda and North American (NA) plates meet, and on the adjacent plate boundaries. The MTJ marks the nexus of the Mendocino and San Andreas faults with the Cascadia subduction zone (CSZ). Historically, most large earthquakes around the MTJ have been within the offshore Gorda plate and its subducted portion beneath the NA plate. North of the MTJ, active faults mapped in the NA plate are part of the CSZ fold and thrust belt. While some events have been detected in the NA plate, no large historic events have been associated with mapped surface faults. The M6.5 earthquake of 21 December 1954 in Humboldt County is one possible exception. Using published data from catalogs and articles, unpublished data from Berkeley's archives, and S-P times interpreted from two United States Coast and Geodetic Survey (USCGS) accelerometers, we determine a probability cloud for the earthquake's hypocenter using NonLinLoc. The highest probability location lies beneath Fickle Hill just east of the city of Arcata, CA, at 40.87°N,

124.03°W, and ~11km depth. Using P-wave polarities from Berkeley stations and the digitized waveforms from the accelerometers, we find that the focal mechanism most consistent with the data indicates indicates thrust movement with strike, dip and rake of 350°, 10°, and 90°, respectively, at a depth of 14km. Given the depth uncertainties of both this event and the megathrust, this implies that the earthquake most likely took place on the subduction interface rather than on the mapped faults in the Mad River fault zone that trend 322° and dip to the northeast. The revisited intensity in the epicentral region also supports a location beneath Fickle Hill, to the east of the city of Arcata, CA.

Introduction

On 21 December 1954, just before noon local time, an earthquake with magnitude 6.5 shook the communities on the North Coast of California surrounding Humboldt Bay (Roberts and Cloud, 1958; Murphy and Cloud, 1984). The shaking in Arcata, CA, Eureka, CA, and nearby areas was much stronger than that of the frequently occurring large earthquakes near the Mendocino Triple Junction (MTJ) or in the Gorda Plate offshore, and caused much damage (Roberts and Cloud, 1958; Murphy and Cloud, 1984; Steinbrugge and Moran, 1957; Hough et al., 2025). This earthquake has been referred to in the literature by several names. In this study, based on the preferred location obtained herein, we refer to it as the Fickle Hill earthquake.

Seismicity in the region was not unexpected by the residents of Humboldt County, at least since the early 1900s; the 1906 Great San Francisco earthquake was felt strongly in the area (Dengler et al., 1992; Toppozada and Barnum, 2004). The region, where three tectonic plates meet, is the most seismically active in California. The nexuses of these plates, the Pacific, Gorda and North American (NA), are the Mendocino and San Andreas faults and the Cascadia subduction zone (CSZ). Additional seismic hazard stems from the many active faults mapped in the NA plate, which are interpreted as part of the CSZ fold and thrust belt (Kelsey and Carver, 1988, Clarke and Carver, 1992). As we now know, the majority of large earthquakes around the MTJ have taken place within the Gorda plate offshore and in its subducted portion beneath the NA plate and along the Mendocino fault. While some events have been detected in the NA plate north of the MTJ, no large historic events have been clearly associated with the mapped surface faults.

The possible exception to the dearth of large earthquakes in the NA plate is the M6.5 earthquake of 21 December 1954. The location and seismotectonics of this event remain enigmatic, as it occurred well before the present era of broadly available, digital seismic data. The earthquake was well-recorded for the time, including by two nearby triggered accelerometers and other stations of the US Coast and Geodetic Survey (USCGS), on seismographs operated by the Berkeley Seismographic Stations (BSS, now the Berkeley Seismology Laboratory (BSL)) of the University of California Berkeley, and the California Seismological Laboratory (CSL) at the California Institute of Technology in Pasadena, CA, as well as at other regional and teleseismic sites. Locations of the earthquake determined in the years following 1954 include those of the BSS (Milne, 1957), the USCGS (USCGS, 1954b), the International Seismological Centre (ISC; ISC, 2025), as well as in a thesis (Tocher, 1956a), several papers which used the earthquake to study "False S" (Cameron, 1961a, 1961b), and a report from the

1970s to understand the seismic hazard related to the Humboldt Nuclear Power Plant (Tenekron Energy Resource Analysts (TERA), 1977). No focal mechanism was ever reported for this event, and with the exception of the TERA report (1977), none of the reported locations included a depth for the earthquake.

The purpose of this study is to collect the available data about the earthquake, and to use modern methods and seismic velocity models to determine an improved hypocentral location including depth, to calculate a moment magnitude if possible, and to estimate the event's focal mechanism. We also revisit the intensity distribution, based on detailed felt and damage reports collected by the USCGS (Roberts and Cloud, 1958; Murphy and Cloud, 1984; Hough et al., 2025), as well as newspaper archives, recently discovered photos, detailed maps of the water supply pipeline for Eureka which broke in the earthquake, and recently collected eyewitness accounts (see Supplemental Information for the contents of the Assembled Dataset and Data and Resources). The goal is to discover whether the earthquake occurred within the mantle of the subducting Gorda plate, on the Cascadia subduction interface, or whether it is associated with a mapped surface fault within the North American plate.

Available Data and Resources

There are a variety of sources of original data relating to the 1954 Fickle Hill earthquake. The original records from the BSS stations operating at the time, as well as the original reading sheets for the event are still present at the BSL (See Data and Resources). The reading sheets also include picks from the seismic stations operated by the CSL. The USCGS operated seismic stations in the Western United States including a "weak motion" station at Ukiah, CA, and two triggered accelerometer stations in the epicentral area at Eureka, CA and Ferndale, CA (EUR & FER; Cloud, 1965). Finally, global arrivals from the event are reported in the 1954 annual Bulletin of the ISC (ISC, 2025), as well as more recently on the ISC website (ISC, 2025). Cameron (1961a) gave S-P times, $t_{S\text{-}P}$, determined from aftershocks at the BSS stations. This plethora of information, for example the arrival picks available in the various catalogs and bulletins and their polarities, as well as the three component waveforms from the two accelerometer stations, have not previously been collected to support a thorough analysis of the Fickle Hill earthquake. We apply current methods and regional velocity models to these data to update the determination of its hypocenter and to determine its focal mechanism. A complete compendium of local, regional and global arrivals for the Fickle Hill earthquake is available at the ISC (ISC, 2025), but the location given there is based on a global solution.

Seismic Records

The BSS operated 11 seismic stations (Table S1) at the time of the Fickle Hill earthquake. We were able to find and scan records from 9 of the stations; the records of the mainshock from COR could not be located in the archive, and the records from SHS are on 35 mm film, the readability of which is limited due to equipment constraints. The closest station to the earthquake was ARC (Figure 2). The collected records were scanned at 1200 pixels per inch (ppi) in 24-bit 3-channel color with a Contex IQ 4400 scanner, and with an original digital format of TIFF that was later converted to JPG. The physical records typically measure approximately 100 cm in length and usually have either 15 or 30 minutes of data recorded on each trace. With a typical length of about 45,000 horizontal pixels, the effective resolution of the scanned data is either 50 or 25 pixels per second for 15 or 30 minute traces, respectively (see Data and Resources). In addition to the records from the mainshock, we collected and scanned the records available for the largest aftershock, M 4.7, which occurred on 30 December 1954 at 09:16:13 UTC. This latter set includes records for the Z and E components at COR, as well as at several other BSS stations. Table S1 includes information on the stations' locations, the equipment operating at the time (Bolt and Miller, 1975) and whether the records were found and scanned.

Our primary use of the scanned BSS records is to read the polarity of the P-arrival (Table 1) for use in determining the focal mechanism, as most of the nearby stations went off-scale immediately following the P-arrival (see for example, Figure 2 (bottom)), although we also include the arrival times used in the analysis for determination of the location. For the purpose of determining the polarities, we assume that the orientations of the sensors given on the records are correct. In addition, for ARC and FER where only horizontal records are available for the P-arrival, we infer the vertical polarity (Table 1) of the arrival from the horizontal records (Plešinger et al, 1986). We also infer the polarity of the P-arrival for MIN from the horizontals, as the arrival on the vertical Benioff channel is not clear due to noise. Finally, we assume the vertical polarity observed for the P-wave of the largest aftershock at COR is the same as it would have been for the main shock.

As we began work on the Fickle Hill earthquake, we were pleased and surprised to receive paper copies of the recordings for the event from triggered accelerometers (L.

Gee, U.S. Geological Survey, oral personal communication, February 2022) of the type USCGS Strong Motion Seismograph (Cloud, 1965) operated by the USCGS in Eureka (EUR) and Ferndale (FER, Figure 3). It appears that these copies were made as part of the effort to digitize the accelerograms in 1969 (Hudson, 1969). The equipment in Ferndale was co-located with the BSS seismographs in the Ferndale City Hall, and the instrument in Eureka was sited in the Eureka Federal Building (now the Eureka Post Office). Information for these strong motion seismographs, including their orientations, is also given in Table S1. This equipment triggers when the ground motion becomes strong enough to close the electric contacts of the pendulum starter. The recording on light-sensitive paper includes both timing marks from a clock mechanism and three components of ground motion (vertical, lateral and transverse to the orientation of the unit). The triggering time for the strong motion seismograph is given as a graph in Cloud (1965). For this analysis, we assume that the instruments trigger on the arrival of the P-wave and that the beginning of the record is 0.5 s after the P-arrival. These records provide two important contributions for our work. The first is that they are close to the earthquake, and they give us an assumed value for t_{S-P}. For FER, we assume that the P-arrival reported for the BSS seismographs also triggered the USCGS accelerometer, while we have no absolute P-arrival time for EUR. The second is that we also have near-complete on-scale waveforms from these two stations close to the epicenter which we can use to estimate the moment magnitude and evaluate possible focal mechanisms for the earthquake. All records from other nearby BSS stations, particularly the closest station to the quake, ARC (Figure 2), immediately go off-scale with the arrival of the P-wave.

To make the data from EUR and FER accessible to modern techniques, we have scanned and digitized these three-component strong-motion records. The paper copies of the records were scanned using a Contex IQ 4400 scanner to create digital copies with a resolution of 1200 dpi and 24-bit color in JPEG format. These records were then analyzed using the DigitSeis tool (Ishii and Ishii, 2022) to extract the accelerogram traces in Cartesian (x,y) coordinates. This output format was necessary due to the lack of helicorder-style minute marks in the individual traces used to assign timing in the DigitSeis software.

While timing could be assigned by linear interpolation between the given start- and end-times of the record, this was avoided due to the possibility of distortion of the paper and its copy in the x-direction (Lee et al., 2022). To minimize timing uncertainty in the record, the presence of time marks which are formatted as horizontal dashes and gaps representing 0.25 seconds in time across the length of the record is leveraged. Particularly, the number of pixels equivalent to an elapsed time of 0.25 seconds is logged as a function of horizontal position throughout the record (Figure 4). This measurement of equivalence between time and pixels is smoothed with a rolling average and utilized to convert the Cartesian coordinates to y-position in pixels as a function of time in seconds. The start time for the trace given on the original record is used to determine absolute time for the data (Figure 4). Additionally, a rolling average is used to smooth the y-position coordinate and determine a zero-line from which amplitude in pixels can be measured. Having generated time-series from the scanned images, the data have been converted into the widely-used SAC format and are available along with the original scans as part of the assembled dataset at the NCEDC (Northern California Earthquake Data Center; see Data and Resources).

Phase Arrivals

Phase arrivals for the Fickle Hill earthquake are reported in the Bulletin of the BSS (Milne, 1957), as well as the Bulletins of the USCGS (USCGS, 1954) and the ISC (ISC, 2025). Rather than use the BSS Bulletin, we retrieved the reading sheets for the event, and used the arrivals reported there, including timing corrections for each station. These scans are available as part of the assembled dataset at the NCEDC (See Data and Resources). For example, for ARC the timing correction is given as +43.2 s. The reading sheets also reported arrivals from CSL stations. In total, we found arrivals for 19 stations. In all cases, we assumed that the corrections for the arrival times related to separation of the "timing source" from the recorder have been properly applied, and that all stations use the same time base. The set of stations which we have used in the analysis and the phase arrival times are given in Tables 1 and 2, respectively. The set of phase arrivals used to relocate the earthquake includes the inferred $t_{S\text{-}P}$ from the accelerometer records at EUR and FER, which provide important constraints for the hypocentral distance. For ARC, estimates of $t_{S\text{-}P}$ for the mainshock range from 2.0 - 2.9 s with an average of 2.5 seconds are based on the values observed for aftershocks in the time following the mainshock (Cameron, 1961a; TERA, 1977). We also use $t_{S\text{-}P}$ given by Cameron (1961a) for SHS, MIN and COR, based on observations of aftershock phase arrivals. Other S-arrival times are given in the BSS reading sheets, and for UKI in the USCGS Bulletin (1954).

Relocation

In the literature, 14 epicenters are given for the Fickle Hill earthquake, clustering between 40.78°N and 124.17°W in the SW and 40.94°N and 124.0°W in the NE. In the printed USCGS report for 1954 (Roberts and Cloud, 1958; Murphy and Cloud, 1984, USCGS, 1954b), three different locations are given, although one of them appears to be a typographic error. The other epicenters stem from the BSS Bulletin for 1954 (Milne, 1957); several locations from the ISC, including the original location in the 1954 Bulletin (2025); Tocher's doctoral thesis (1956a) and Cameron (1961a).

To ensure that the hypocenter of the relocated Fickle Hill earthquake is consistent with current locations for Northern California seismicity reported by the Northern California Seismic System, we use only the regional arrivals to a hypocentral distance of about 810 km – those for the BSS and CSL stations, and the Ukiah, CA (UKI), station of the USCGS – for 19 stations in total (Table 1). We use a smooth P-wave velocity model (Table 2, Supplemental Figure S2) derived from the mean of slowness with depth from two models for the Mendocino area: a representative depth profile from Henstock and Levander (2003) and the MEN2 model from (Oppenheimer et al., 1993). Such a smooth model avoids location artifacts at layer interfaces. The uncertainties for P- and S-arrivals are set to ±1 sec and ±2 sec, respectively. For EUR, which does not have absolute timing, only the t_{S-P} difference is used to constrain the location. For FER we use the P-arrival time from the BSS equipment and t_{S-P} from the co-located USCGS accelerometer.

We relocate the 1954 event applying the NonLinLoc (NLL) algorithm (Lomax et al., 2000, 2014) to a 200 km x 200 km area centered on latitude 40.4°, longitude -124.4°, with test depths ranging from 0 km to 40 km. This algorithm requires a large suite of travel times from each station to the test hypocenters within the model space. To calculate the P travel times, we use a finite-difference, eikonal-equation algorithm (Podvin and Lecomte, 1991), and divide these values by a constant v_P/v_S=1.78 to calculate S travel times. The travel time uncertainty along each path is assumed to be 2% of the calculated travel time, with minimum and maximum permitted values of 0.05 s and 2.0 s, respectively. This effectively performs distance weighting related to the length of each path.

The NLL algorithm (Lomax et al., 2000, 2014) uses efficient global sampling algorithms to obtain an estimate of the posterior probability density function (PDF) in 3D space for the absolute hypocentral location. This sampling uses the octree cascading grid search (Lomax et al., 2014), so the finest scale grid spacing is very small relative to the search volume and to the uncertainties in the location. For example, at the depth of location with the highest probability and at the other tested depths, the spacing of the search grid was ~300m. The location PDF provides a complete description of likely hypocentral locations and includes comprehensive uncertainty information. Within NLL, we use the equal differential-time (EDT) likelihood function (Zhou, 1994; Font et al., 2004; Lomax, 2005, 2008; Lomax et al., 2014) which is very robust in the presence of outlier data caused by large errors in the arrival-time picks. Since outlier picks are frequent in phase data from the instrumental period before the 1960s due to timing problems and other challenges, such as difficulties in picking phases on paper and other analog records

(Adams, 2004), the robustness of the EDT likelihood is important for this study of the 1954 event.

Figure 5 shows the cloud of probable locations and their relationship to the three closest stations, ARC, EUR and FER. The hypocentral solution with the highest probability, the "most likely" location, is at 40.87°N , 124.03°W, and at a depth of ~11 km, with horizontal and vertical uncertainties of ±12.3 km and ±15.1 km, respectively (Table 1, Figure 5). This is just 3.9 km east-southeast of the station ARC in the city of Arcata, CA, beneath Fickle Hill, both a community east-southeast of Arcata and the name of a hill. The Fickle Hill fault in the NA plate, part of the Mad River fault zone, transects the hill from southeast to northwest, with an approximate trend of 322° (USGS and CGS, 2025).

The densest part of the PDF of possible locations (Figure 5, red dots) describes an east-west trending ellipsoid which is shallower in the east and deeper as it approaches ARC. The $t_{S\text{-}P}$ values from the accelerometer records from EUR and FER and their uncertainties contribute important constraints to the PDF. The east-west trend and the north-south width of the PDF essentially describe an arc centered on FER and defined by the uncertainty in its $t_{S\text{-}P}$ value. The east to west dip is controlled by the $t_{S\text{-}P}$ value from EUR, which defines the maximum probable hypocentral distance $\sqrt{h^2 + d^2}$, where h is the hypocentral depth and d is the epicentral distance. Thus, if the hypocenter is more distant from EUR, then it must be shallower. Conversely, if the hypocenter is closer to EUR, it must be deeper. The length of the ellipsoid in the east-west direction is also determined by $t_{S\text{-}P}$ at EUR. Both the most likely hypocenter and the trend of the probability ellipsoid are consistent with $t_{S\text{-}P}$ observed from the aftershocks recorded at

ARC (Cameron, 1961a, TERA, 1977). Indeed, if we include t_{S-P}=2.5 s for ARC given in Cameron (1961a), in calculating the hypocenter, the cloud of possible locations (red dots) tightens considerably, but the most likely solution does not change. Overall, the shape and location of the probability cloud depend strongly on the velocity model, the quality and distribution of phase picks, as well as the location algorithm and the specific settings of other parameters, such as the uncertainty assigned to the arrival times. This means that the cloud generally favors a depth ≤ 20 km for the event, and an epicenter along a west-east trending patch within ~10km of ARC. It is difficult to say more, because of trade-offs and uncertainties in the various parameters. A NLL solution for the hypocenter determined only using only the information from the nearest three stations, ARC, EUR and FER, exhibits the same trends as the overall solution, with the exceptions that the cloud of probabilities is slightly less dense than the solution presented above and lies slightly more to the north.

Focal Mechanism, Magnitude and Stress Drop

To determine a focal mechanism for the Fickle Hill earthquake, two types of data are available; the observed and inferred polarities of the first onsets from the records of the BSS stations, and the waveforms from the two USCGS accelerometer stations, which do not include the P-arrival. For the former, only the polarities are available, and for most stations the trace on the light-sensitive paper disappears almost immediately because the light tracking the onset was moving so quickly. The polarity is only visible by carefully examining the record, especially by magnifying the section of the record with the first onset (Figure 3c). In the cases of four stations, ARC, FER, MIN and COR, we have inferred the vertical polarity, as described above, based either on the horizontal records or for the last, based on the record of the largest aftershock.

To determine the probable focal mechanism, we need to evaluate the possible l locations as a function of depth due to the east-west deepening trend in the hypocentral locations. Thus, for each of the fixed test depths to be used in the search for the focal mechanism (1.5, 3.5, 5.5, 8, 11, 14, 18, 21, 24, 27 and 30 km), we calculated the most likely hypocentral location (Table 3) and the concomitant azimuths and take-off angles for each of the stations. Note that the latitudes of the most likely hypocentral locations at all of the test depths (Table 3) lie to the south of the latitude of the closest station ARC, 40.878°. Hypocenters to the southeast of ARC are inconsistent with its horizontal P-wave vector, which has negative onsets on both horizontal channels (Plešinger et al. 1986). Source locations consistent with this observation must lie either to the southwest of ARC, and the vertical P-arrival would be negative, or to the northeast of ARC, in which case the vertical P-arrival would be positive (Plešinger et al, 1986).

Using the most probable hypocentral location for each test depth (Table 3, Figure 5), we first examine the polarities (Table 1). In particular, for the stations ARC and FER, which only have horizontal sensors, and for MIN where the vertical record is very noisy, we infer the polarity of the vertical onset of the P-wave based on the location of the preferred hypocenter at each depth using the horizontal vector of the P-wave (Plešinger et al. 1986). As the distance to FER is on the order of 40 km, the azimuth does not change very much for the various test hypocenters. However for ARC, which is much closer, the azimuth does change. All of the most likely test hypocenters (Figure 5, Table

3) lie slightly south of the latitude of ARC, and get deeper as they pass from east to west. Since only the hypocenters located to the west of ARC are consistent with the negative polarities observed on both its N and E channels,Thus, we have chosen to add two test locations to the northeast of ARC at approximately same distances and depths as the southeast test locations at 11 km and 14 km depth. The ARC polarity for these two sites will be positive. These two points lie slightly north of a line trending N70E from ARC. We selected these positions, as the arctan of the first motions observed in many of the aftershocks suggested sources at varying distances lying between N60E and N70E of ARC. These two test hypocenters are consistent with the most probable region of the cloud of hypocenters determined using only the P-arrivals and S-P times for ARC, EUR and FER. The two closest stations with polarities, ARC and FER, have upgoing takeoff angles for all the test hypocenters, while the takeoff angles for all other stations have downgoing values.

The observed and inferred first motions polarities are not consistent with a strike-slip focal mechanism at any depth, such as would be expected if the event had taken place within the Gorda plate, like the earthquakes of December 2021 and 2022 (Figure 6(B); Supplemental Figure 2; Hellweg et al., 2024; Yeck et al., 2023; Yoon and Shelly, 2024; Shelly et al, 2024, Guo et al., 2024), or on a theoretical nearby fault with movement such as that observed along the Mendocino fault (Figure 6C; Supplemental Figure 2).

We estimate the focal mechanism and scalar seismic moment of the event using a forward modeling approach in which local and regional distance vertical component P-wave polarities are fit simultaneously with the three-component accelerometer waveforms recorded at the stations EUR and FER. The data from these latter two stations were digitized and instrument-corrected as previously described. For the determination of the focal mechanism, the acceleration records were integrated to ground velocity. Velocity Greens functions were calculated using the GIL7 velocity model (Table 3; Supplemental Figure 3; Dreger and Romanowicz, 1993) using Herrmann's (2013) FK-integration program. The GIL7 velocity model is appropriate for the region and is used for routine moment tensor estimation at the BSL (e.g. Romanowicz et al., 1993; Pasyanos et al., 1996). Synthetic seismograms were computed from the Greens functions. The first step was to convolve them with a trapezoidal source time function with a rise time of 0.05, a high time of 0.7 and a decay time 0.5s. Then the strike, dip, rake and scalar moment source parameters were iteratively adjusted and the corresponding fits inspected. The data and synthetics were both bandpass filtered between 0.1 to 0.5 Hz using an acausal 4-pole Butterworth filter. The trapezoidal source time function is needed to account for the source duration at these two close stations, and the trapezoidal source time function parameters were adjusted by forward modeling to best fit the waveshape in the modeled passband.

Figure 6(A) shows the most convincing results in which a north-south striking, low-angle reverse focal mechanism for the source to the northeast of ARC at 14 km depth satisfies both the first-motion polarity data and the three-component waveforms for EUR and FER reasonably well. The source parameters are strike/dip/rake=350/10/90 degrees and a scalar moment of 5E+18 Nm (M_w=6.4). The moment magnitude is consistent with M_L=6.5 determined in 1954 by the BSS. The depth of 14 km can be considered to be the depth of the main moment release or the slip centroid.

This determination of the focal mechanism is not well constrained given the sparse data, and it is not possible to formally assess the uncertainties. In order to illustrate that the data preferentially support this low angle focal mechanism, we compare its fit to examples of the more typical strike-slip focal mechanisms observed in the area, a west-east striking 'Mendocino fault', and a northeast-southwest striking Gorda intraplate fault (Figure 6(B) & (C); see Supplemental Information; Hellweg et al., 2024; Yeck et al., 2023; Yoon and Shelly, 2024; Shelly et al, 2024). We also show an example for the fits to a thrust focal mechanism consistent with the Fickle Hill fault mapped in the NAP.(Figure 6(D); Supplemental Figure S1). This fault has strike tending trending 322° and steeper dip than the best fitting focal mechanism. Note also that the positive polarity at FER lies outside the compressional region of the focal mechanism, and the fits to the waveforms at EUR and FER are not as good as those in Figure 6(A).

Finally, we estimate the stress drop for the Fickle Hill earthquake using the transverse component velocity spectra derived from the records at EUR and FER (Figure 7, black lines). The basis for the analysis is again broadband Greens functions generated using the GIL7 velocity model. From them, we estimate the spectrum of an average focal mechanism (red lines) by sweeping through the mechanism space and using the spectral shape of Boatwright (1980). The modeling reveals a high frequency falloff exponent of 2.8 and corner frequencies of 0.69 and 0.69 Hz for EUR and FER, respectively (Figure 7). These corner frequencies are consistent with the short duration of the primary S-wave pulse observed in both the velocity and displacement records. From this analysis the moments for the stations EUR and FER are 3.3e18 N-m and 6.9.e18 N-m, respectively. These moments bracket the value from the mechanism fitting. It is noted that FER can be better fit with a higher moment but we capped it at Mw6.5 based on the other magnitude estimates. There are likely unaccounted for site effects at the higher frequencies used to the spectral fitting. Assuming a directivity model using fault dimensions from Leonard (2010) we calculated a directivity correction factor relating the observed corner frequency to that expected for a perpendicular observation of the rupture. This reduces corner frequencies by factors of 0.357. The resulting Brune stress drops are 6.5 MPa for EUR and 13.5MPa for FER. These raw stress drops are high owing to the very short widths of the S-wave pulses and the corner frequencies, which are high for an earthquake with M_W~6.5. It is noted that there is considerable uncertainty in the corner frequency and therefore stress drop owing to site effects which are not accounted for, the assumed directivity correction, and the moment scaling of the spectra. Although the data are too sparse to uniquely determine the rupture plane, the ENE dipping plane is the most probable rupture plane in that a rupture toward the southwest and updip toward EUR and FER could explain the short duration of the S-wave pulses and the high measured corner frequencies. The more steeply dipping plane does not allow rupture toward those stations.

Macroseismic Data

At the time of the 1954 earthquake, the U.S. Coast and Geodetic Survey (USCGS) collected macroseismic data using postcards, typically left at Post Offices (Byerly and Dyk, 1936). These data were summarized in the United States Earthquakes publication series (see Data and Resources). More complete summaries were presented in a preliminary, lesser-known report series: “Abstracts of Earthquake Reports for the Pacific

Coast and Western Mountain Region" (hereinafter the Abstract Series). For the Fickle Hill earthquake, USCGS (1954a) included reports from over 500 locations, including 130 locations where shaking was reportedly not felt, and dozens of reports from the Eureka/Arcata region with street addresses included. With respect to spatial sampling at the ZIP-code scale, the volume and completeness of this dataset rivals modern Did You Feel It? data (Dengler and Dewey, 1998; Wald et al, 1999) from the region.

Previously published macroseismic data are presented in a readily accessible format and discussed in detail by Hough et al. (2025), including newly interpreted intensities using the Modified Mercalli Intensity scale (hereinafter MMI; Richter, 1958). Interpreted intensities are close to values assigned by USCGS (1954a), differing on average by less than ¼ unit. To obtain preferred intensity values, intensity assignments are averaged with original USCGS (1954a) values.

Based on the standard intensity questionnaire, with dense spatial sampling, the resulting set of intensities is far more complete and reliable than intensities gleaned from media accounts, with the usual tendency of media reports to focus on the most dramatic effects (Hough, 2013). Media and eyewitness accounts can, however, provide important additional information from the near-field region. In an ongoing parallel effort, we (LD) have collected accounts from individuals who experienced and remember the earthquake and are included in our characterization of near-field intensities.

Lastly, the intensity distribution includes instrumental intensity values estimated from the triggered strong motion recordings from EUR and FER. We follow the standard ShakeMap recipe, estimating MMI 7.0 and 6.6 at Eureka and Ferndale, respectively. These values are slightly higher than, but generally consistent with, the average values inferred from the USCGS (1954a) reports. We use the intensity distribution to generate ShakeMaps (Figure 8), again following standard modern conventions (Worden et al., 2020). The intensity distribution confirms the instrumental results in several ways. First, although accounts are concentrated in the larger cities near the coast (Eureka, Arcata, and Ferndale), the strongest documented shaking was east of Arcata, supporting the hypocentral location under Fickle Hill. Secondly, although shaking throughout the region was strong enough to damage masonry chimneys, the strongest documented shaking implies MMI 8 to perhaps 8.5. The paucity of higher intensities is consistent with a depth of moment release around 14 km, with intensities providing weak evidence for a somewhat deeper depth (Hough et al., 2025). The intensity distribution is consistent with expectations for Mw 7.0, supporting the observed higher than average stress drop (Hough, 2025), although source directivity may also be a factor. A striking number of accounts specifically note that shaking felt especially “rapid.” This suggests relatively strong high frequency energy, and is likely to be a consequence of the very short observed S-wave pulses at EUR and FER, the higher than average stress drops modeled from those stations and the onshore location, which puts the event much closer to, indeed beneath, the population centers than would the offshore Mendocino fault and Gorda intraplate events commonly felt in the area.

Source Mechanism and Stress Drop

In the years since the scientific community has begun to better understand the complex tectonics of the MTJ and the region, the Fickle Hill earthquake has remained an enigma (Dengler et al., 1992). Although there is a consensus that it occurred onshore, insufficient analysis had been done to determine its source fault. Two important pieces of information have been missing, the hypocentral depth of the event and its focal mechanism. In our reanalysis of the event, two factors suggest that the hypocenter is not within the subducting Gorda plate or its mantle. First, the event's probable depth is too shallow; the subduction interface in the area lies between 15 and 20 km below the surface, dipping from west to east (Hayes et al. 2018). The uncertainties in the depths, whether of the most likely hypocenter at 11 km, or of the moment release, 14 km are large. They suggest, however that the earthquake is more likely to lie at or above this interface. Second, given the distribution of observed positive polarities of the P-onsets at the regional stations, a strike-slip focal mechanism, like those commonly observed in the Gorda events, is extremely unlikely. Rather, the 1954 Fickle Hill earthquake was determined to be a thrust event. To demonstrate that typical strike slip focal mechanisms from the region do not satisfy the data, we prescribe the focal mechanism to approximately match that of the 20 December 2022 main shock (Hellweg et al., 2024) or some other theoretical nearby fault with the orientation of the Mendocino fault. Clearly, neither the P-wave polarities nor the waveforms are fit (Figure 6(B),(C), and Supplemental Information).

Excluding the possibility of an intraplate Gorda event leaves two possible sources: A reverse fault associated with the mapped North American plate faults or a shallow east-dipping thrust fault associated with the subduction interface. Choices for the North American plate fault could be any fault in the Mad River fault zone to the east of Arcata, including the Fickle Hill fault. These faults all trend northwest-southeast at approximately 322°, and dip to the northeast (USGS Q faults and CGS). The "elephant in the room" fault is the Cascadia subduction interface. Its strike is close to north-south and it dips at about 11 degrees to the east in this area (Hayes et al. 2018).

Let us consider the suite of most likely locations at the test depths determined through NLL analysis (colored dots in Figure 5). All these locations lie to the southeast and southwest of the station ARC. The locations to the southeast are at depths shallower than 14 km, but are inconsistent with the observed polarities of the P-arrival on the N and E horizontal sensors at ARC (Plešinger et al., 1986). For the locations to the southwest, the depths are 18 km and greater. For these locations, however, the inferred polarity for the vertical motion at ARC would be the only negative first motion (see Supplemental Information, Plešinger et al., 1986) among all the observations. Nonetheless, the focal mechanisms that fit both the polarities and the waveforms at the test depths of 18 km and 21 km best are also north-south striking thrust faults with shallow dip to the east (see Supplemental Information). These locations are quite deep, however, at or below the region of dense hypocenter probability. This, along with the inferred negative vertical polarity for ARC is concerning, and arguably inconsistent with the distribution of other polarities and any focal mechanism considering the complete distribution of polarity data.

The range of likely hypocenters in the dense region of the probability cloud is relatively broad and includes space to the northeast of ARC. Thus, we chose to explore sources in this quadrant, at depths of 11 km and 14 km close to the most likely hypocenter. For the chosen locations, approximately N70E of ARC, the best fitting focal mechanisms also exhibit the strike and dip of the Cascadia subduction interface. For solutions at both depths, all the observed and inferred P-wave polarities are consistent with the focal mechanism and the waveform fits are reasonable (Figure 6, see Supplemental Information). We find the fits slightly better for the 14 km depth than for 11 km, as well as better agreement between the moment magnitude and the BSS reported M_L.

We considered the Fickle Hill fault, or one of the other Mad River fault zone members as a possible source for this earthquake, with a strike of 322° and a dip of 30°. The fits to the waveforms from EUR and FER are not as good as for the north-south striking and shallowly dipping solution (see Supplemental Information). However, the big discrepancy is that the inferred vertical polarity for the P arrival at FER is not consistent with the focal mechanism. An argument similar to that made for ARC and the shifting of the test hypocenters location is not valid, as the change in the azimuth from the event to FER is only very small for all of the test hypocenters used in the focal mechanism analysis, so any choice of hypocenters from the region of likely sources would still exhibit the same inconsistency.

Thus, we find that the Fickle Hill earthquake is most likely to have ruptured the Cascadia subduction interface. The orientation of the focal mechanism that best fits both the P-wave polarities and the recordings from EUR and FER (Figure 6(A)), has a strike, dip and rake of 350°, 10° and 90°, respectively, with the centroid of release at a depth of 14 km. Interestingly the 1992 M=7.2 Cape Mendocino earthquake is shares at least three characteristics with the 1954 Fickle Hill event. These are its source mechanism, its depth, and its location at or above the decollement (Oppenheimer et al., 1992). The 1992 event had a hypocentral depth of about 14 km and exhibited a reverse mechanism with a plane dipping shallowly to the east consistent with the megathrust. Velasco et al. (1994) calculated a stress drop of 90 bars. Ironically, it is still being debated whether the 1992 event was above the megathrust or in the North American plate, as details of the depth of the megathrust throughout the area are not well known. These are similar to the problems we face in understanding the Fickle Hill quake. Finally, although high stress drop is more characteristic of intraslab earthquakes than plate interface events (Strasser et al., 2010), a detailed investigation of the Northern Chilean subduction zone found a range of stress drop values for events along that subduction zone (Folesky et al., 2023). Details of the rupture mechanism aside, the 1954 Fickle Hill earthquake represents an especially hazardous class of events for the region, with both an onshore location and a high stress drop.

Conclusions

Fourteen or more locations have been given in the literature for the Fickle Hill event of 21 December 1954 (Roberts and Cloud, 1958; Murphy and Cloud, 1984; U.S. Coast and Geodetic Survey, 1954a Milne, 1957; Tocher, 1958a, 1958b; Cameron, 1961a, 1961b; TERA, 1977; USGS, 2017; ISC, 2025). With the exception of the ISC-GEM location given in ComCat (last updated on 2023-10-18, last visited on 1 February 2025; USGS, 2017) and at the ISC (2025), and that in the TERA report (1977), these locations were mostly calculated in the 1950s with the analysis methods in use at the time and are lacking an estimate of the event's depth. The ISC-GEM location used a global velocity model and was strongly influenced by many teleseismic phases.

We present a re-examination of the extant and accessible pre-digital data associated with the Fickle Hill earthquake, including previously unused but high-quality accelerograms, and the application of modern methods, tectonic understanding and seismic velocity models. The results have contributed new insights into its source, which is quite possibly the Cascadia subduction interface, making the 1954 earthquake the first large event to be documented in the instrumental era centered on the locked boundary.

While the precision and accuracy of analog-era seismic data is lower relative to modern data products, the cutting-edge methodologies, computational power, and data-access of the period were also crude relative to modern standards. Hence, as is demonstrated here, application of modern tools and techniques to this historical data can yield new and valuable results that leverage the previously unrealized, inherent value of legacy data.

Similarly, for many US earthquakes in the 1930s through the 1960s, high quality and high density felt and damage reports collected by the USCGS are available for reevaluation that may contribute to improving the understanding of those earthquakes. Reviews of existing information such as this study can result in improving regional tectonic insights and thereby also the estimation of hazard.

Finally, our study of the 1954 Fickle Hill earthquake provides a template for the re-examination of other significant earthquakes of the pre-digital age. Careful analysis of archival records and the application of modern analytic methods can reveal new insights into tectonic regimes.

Data and Resources

Background data and archival material used in this study have been compiled and are available in an Assembled Dataset at the Northern California Earthquake Data Center

(NCEDC, https://ncedc.org/pub/assembled/Fickle_Hill_1954/ (NCEDC, 2014, doi:10.7932/NCEDC, last accessed June 2025). This material includes scans of all collected seismograms from the event and its largest aftershocks from the BSS stations; scans of the USCGS accelerograms for EUR and FER as well as the digitized data in the form of SAC records; scans of the BSS recording sheet pages for the event; scans of the 1954 BSS Bulletin (Cover page, page providing hypocenter and origin time, and the page(s) providing arrivals); scans of the ISC 1954 Bulletin pages (Cover page, page providing hypocenter and origin time, and the page(s) providing arrivals); and scans of the USCGS 1954 Bulletin pages (Cover page, page providing hypocenter and origin time, and the page(s) providing arrivals). It also includes a table of the new intensity information gathered from newspaper archives, damage maps and eyewitness accounts.

Digital copies of the Abstracts of Earthquake Reports series can be found online at the Hathi Trust (https://babel.hathitrust.org/cgi/pt?id=uc1.31822006834931&seq=7, last accessed 25 June 2025), a digital library that now preserves over 18 million books and other items, with the fullest access allowable by U.S. copyright law. Original macroseismic data for the 1954 earthquake are published in USCGS (1954).

Supplemental Material for this article includes Figures S1 (Observed (black) and synthetic (red) waveforms and first motion observations for hypothetical earthquake focal mechanisms) and S2 (a plot of the velocity models referred to in the text). Table S1 details hypocentral locations for the Fickle Hill earthquake given in the literarture; Table S2 gives information about the seismic stations used in this study; and finally, Table S3 gives intensity estimates based on the reports gathered from eyewitnesses, newspapers and other historical sources. Appendix S1 lists the resources in the Assembled Dataset at the NCEDC (https://ncedc.org/pub/assembled/Fickle_Hill_1954/).

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Figures

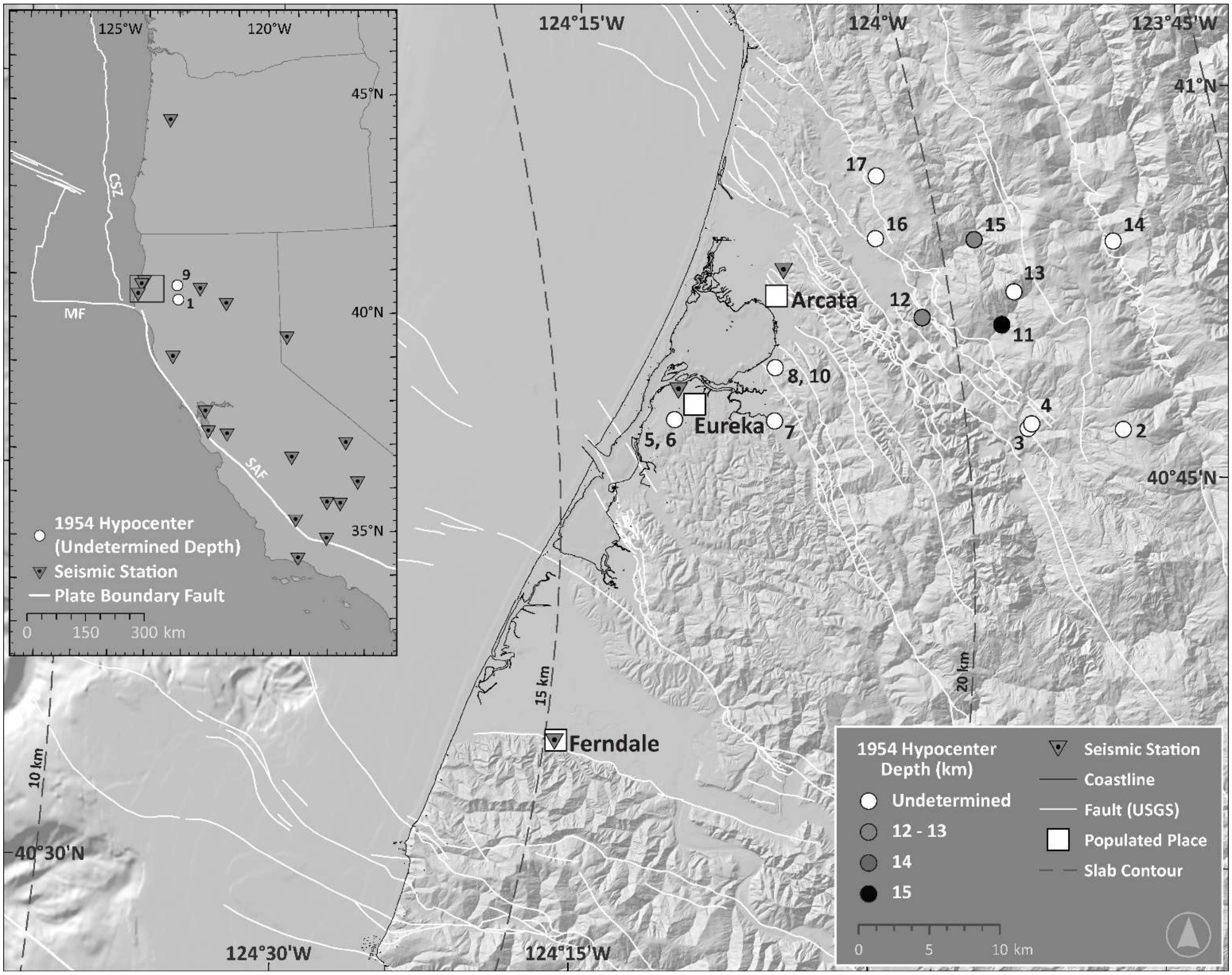


Figure 1: Historical hypocenters (numbered circles) and seismic stations (inverted triangles) used in the study. The insert shows an overview of the region including the plate boundary faults (San Andreas (SAF), Mendocino (MF) and Cascadia Subduction Zone (CSZ); Coffin et al, 1998), with the zoomed area indicated by the box. The stations used in the study are in California, Nevada and Oregon (Table 1) and are operated by the University of California's Berkeley Seismographic Stations, the California Seismological Laboratory at the California Institute of Technology and the United States Coast and Geodetic Survey. The two easternmost historical locations for the 21

December 1954 earthquake are shown on the insert map (white circles).The main map shows a view of the hypocentral region, including mapped faults in the North American plate (white lines; USGS and CGS, 2019), the locations of the cities of Arcata, Eureka and Ferndale (white squares), and the locations of the three seismic stations nearest the event, ARC, EUR and FER (inverted gray triangles). The contours of the 15 km and 20 km depths of the CSZ slab from the Slab2 model (Hayes, 2018) are shown as dashed lines. Historical hypocenters are also shown (circles), with colored circles indicating those that include an estimate of event depth. The numbers indicate which organization or person calculated the location and the reference which documents each hypocenter (See Supplemental Information). Onshore elevation information are from USGS (2009) and offshore depths are from Ryan, et al. (2009).

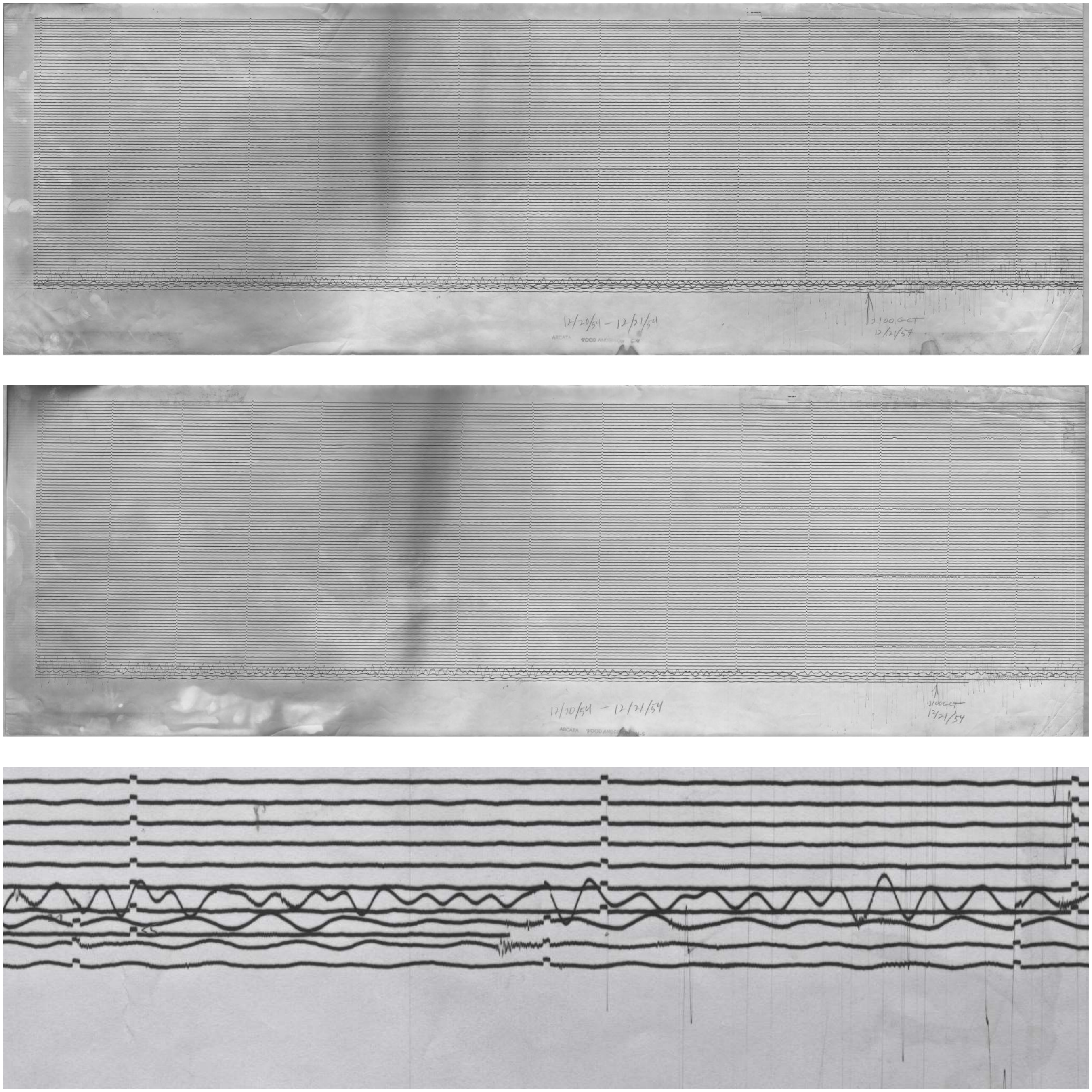


Figure 2: Records from the stations ARC, located in Arcata, CA, on the grounds of and operated collaboratively with what was then Humboldt State College (now Cal Poly Humboldt). Top: Record of the EW oriented Wood-Anderson (WA) seismograph starting at 20:55 UTC on 20 December 1954. Center: Record of the NS oriented WA seismograph starting at 20:55 UTC on 20 December 1954. Bottom: First onset from

ARC-EW. Note that on both records between the onset of the Fickle Hill earthquake and the time the light rays were slow enough to be recorded on the paper again, their position relative to the recording drums changed. This can be seen because after the onset, the minute marks are no longer aligned, and several of the traces overlap the previous traces, as is apparent in the blowup of the ARC-EW record, as well as in the full records of the EW and NS seismometers above. This may have been due to power failure and/or shifts in the instrumentation.

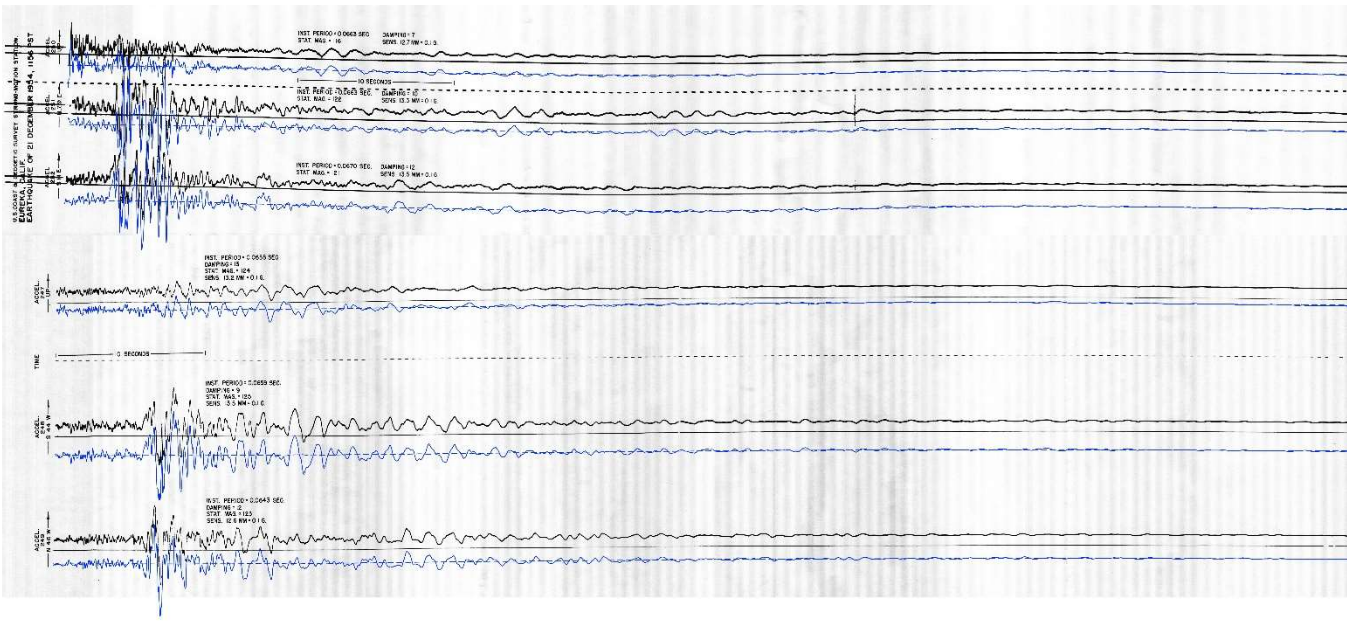


Figure 3: Scans of paper three-component accelerograms from EUR (top) and FER (bottom). Blue traces show the digitized coordinates of the waveforms and are offset down for ease of comparison to the original paper records.

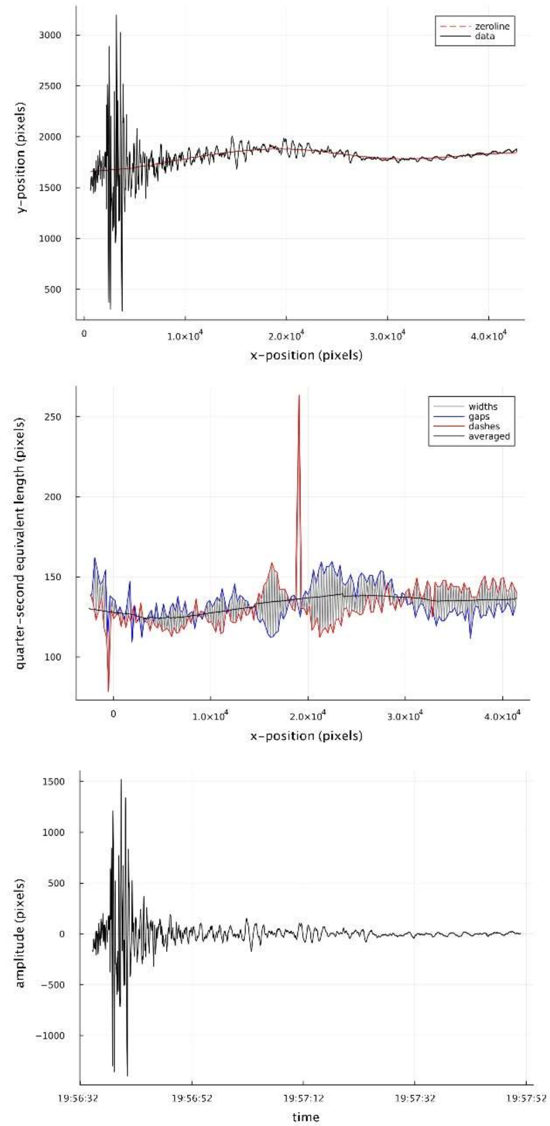


Figure 4: The processing of the digitized trace for the N79E component of motion at EUR. (top) Trace in cartesian (x- and y-position) coordinates as extracted from scans (black) and the zero-line determined using a rolling average (dashed red). (middle) The width of one-quarter second measured in pixels used to assign timing to the traces; values for all widths (gray), gaps (blue), dashes (red), and their rolling average (blue) are given as a function of the x-position on the scan. (bottom) The trace given as amplitude as a function of time after subtraction of the zero-line and time-assignment.

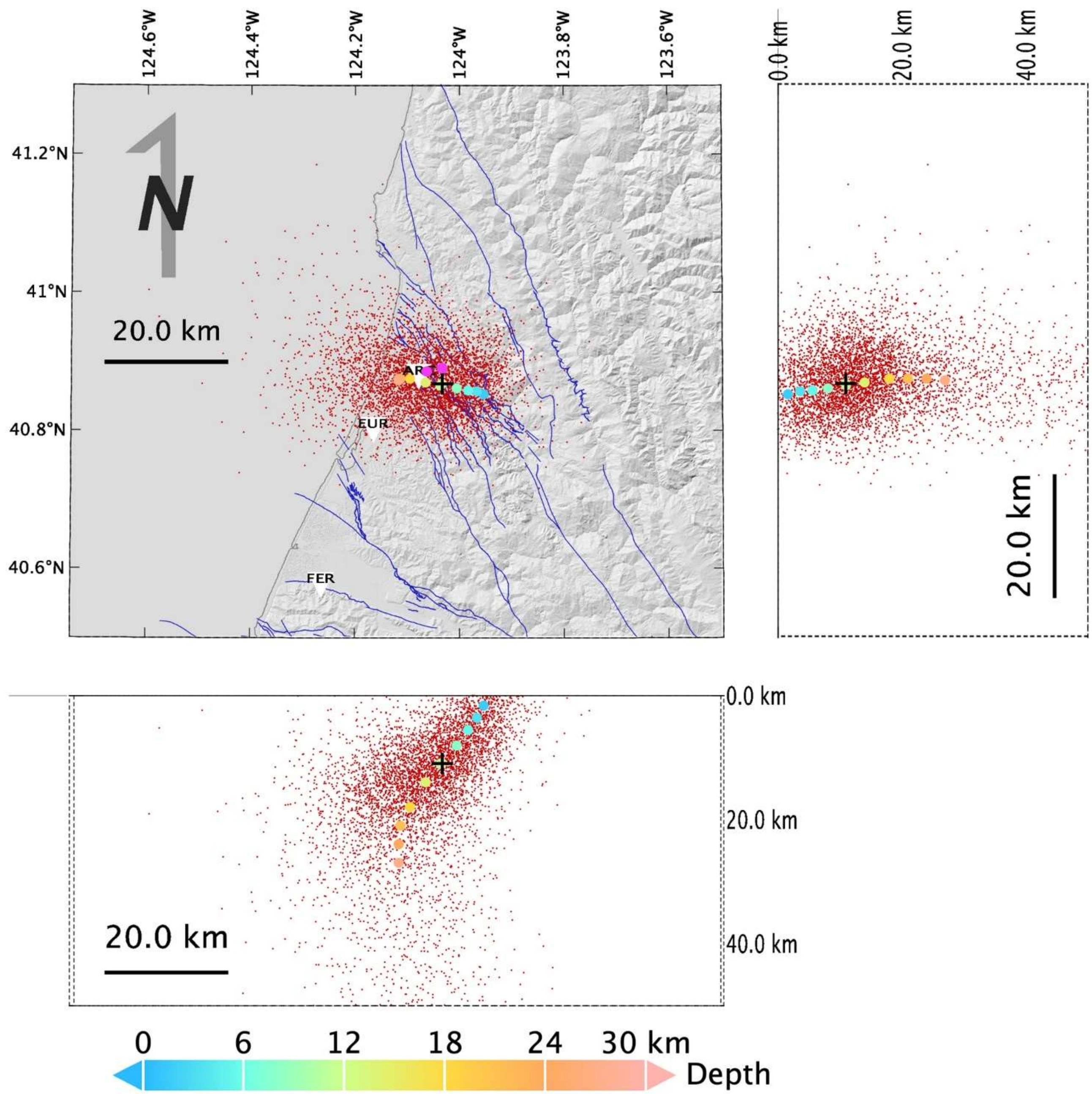


Figure 5: Probability of likely hypocentral locations for the M6.5 Fickle Hill earthquake determined using the NonLinLoc method (Lomax et al., 2000, 2014). Views from above (center), south (bottom), east (right). The locations of the three nearest stations, ARC, EUR and FER, are shown as inverted triangles. In all three views, the most likely location is shown by the +-sign, and the dots show most likely locations at depths of 1.5

km, 3.5 km, 5 km, 8 km, 11 km, 14 km, 18 km, 21 km, 24 km, 27 km, and 30 km. These locations are all to the ESE of the station ARC. The magenta dots show likely hypocenters to the ENE of ARC at depths of 11 km and 14 km, respectively. Dark lines represent the mapped faults in the North American plate (See Data and Resources)

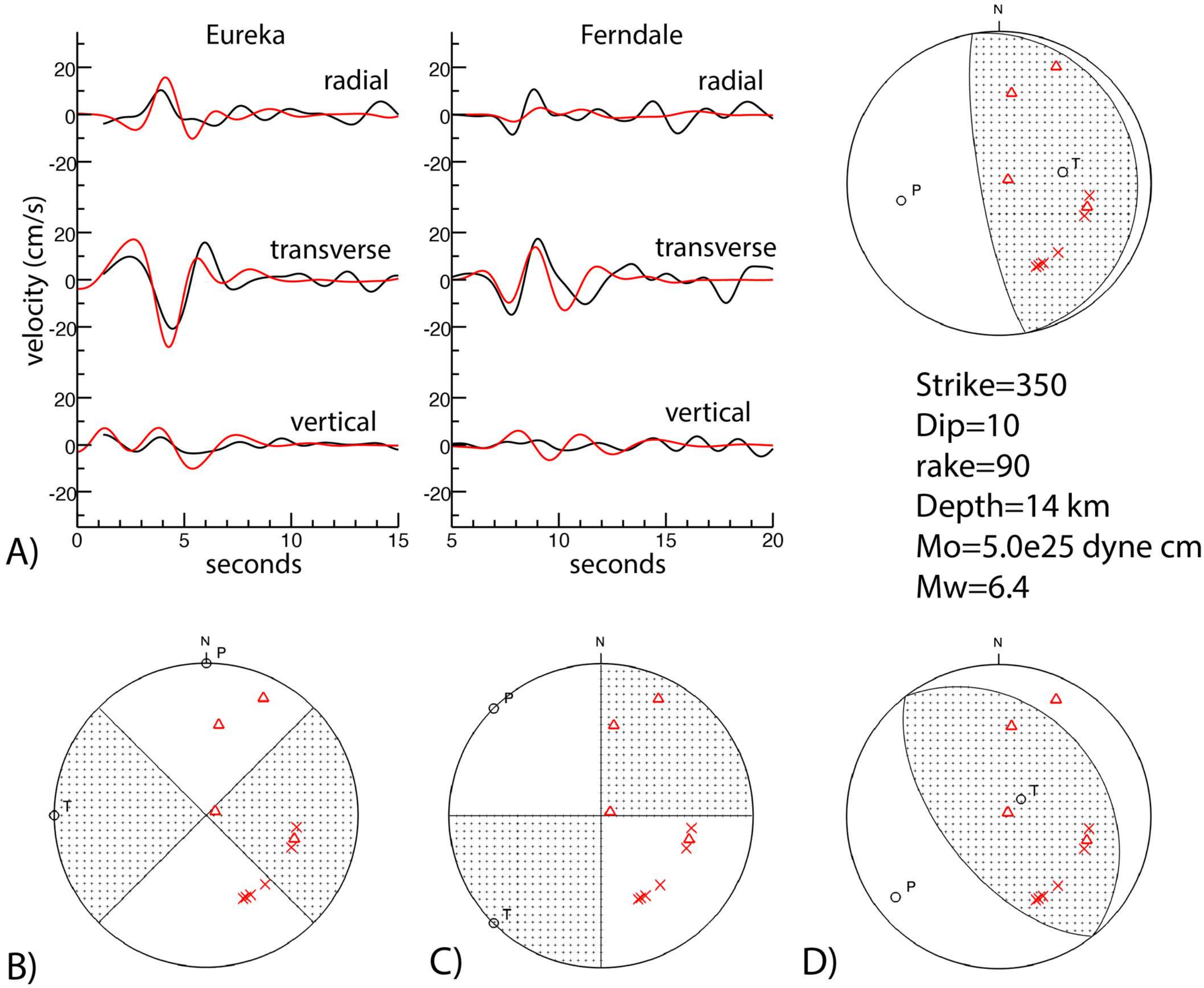


Figure 6: (A) Mechanism for the 1954 event for a centroid of release at a depth of 14 km to the northeast of the station ARC. Left: Observed (black) and synthetic (red) waveforms at Eureka (EUR) and Ferndale (FER) have a good level of fit in the 0.1 to 0.5 Hz passband. Right: The best fit mechanism showing observed and inferred P-wave polarities. Red symbols denote up first motion and green down (no down first motions are observed in this case). "X" shows polarities directly observed on vertical components, whereas triangles show vertical polarities inferred from the observation of the two horizontal P-wave polarities. The circles indicate the P and T axes. (B), (C) and

(D) Sample mechanisms for the same hypocentral location for mechanisms typical of a Gorda intraplate event, a Mendocino fault event and an event on the Fickle Hill fault or one of the other faults in the North American plate, respectively. The symbol key is the same as for (A). Waveform fits for EUR and FER for these mechanisms are shown in the Supplemental Information.

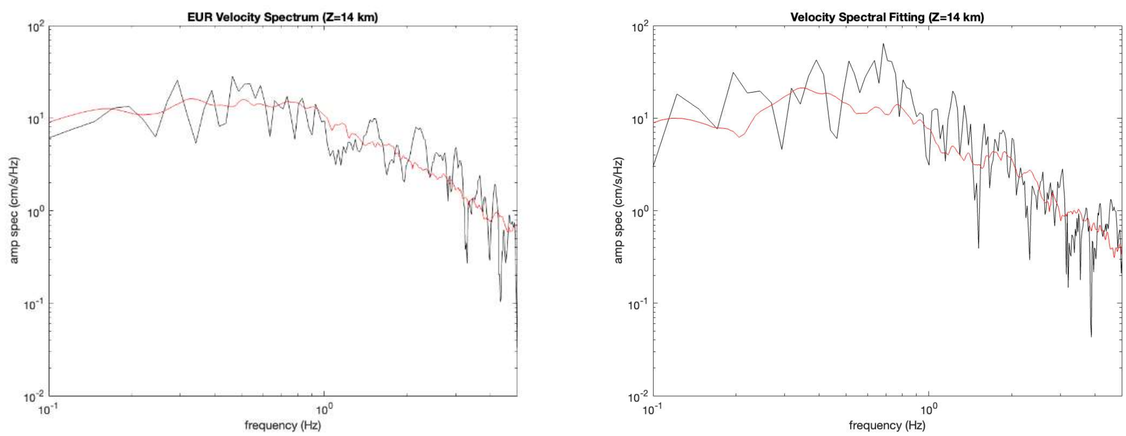


Figure 7: Spectral fits for stress drop analysis for the waveforms from EUR (left) and FER (right). Black lines show the velocity spectra determined from the integrated accelerograms of the transverse motion at each site. Red lines are the best fit Boatwright (1980) spectrum. See text for detailed explanation.

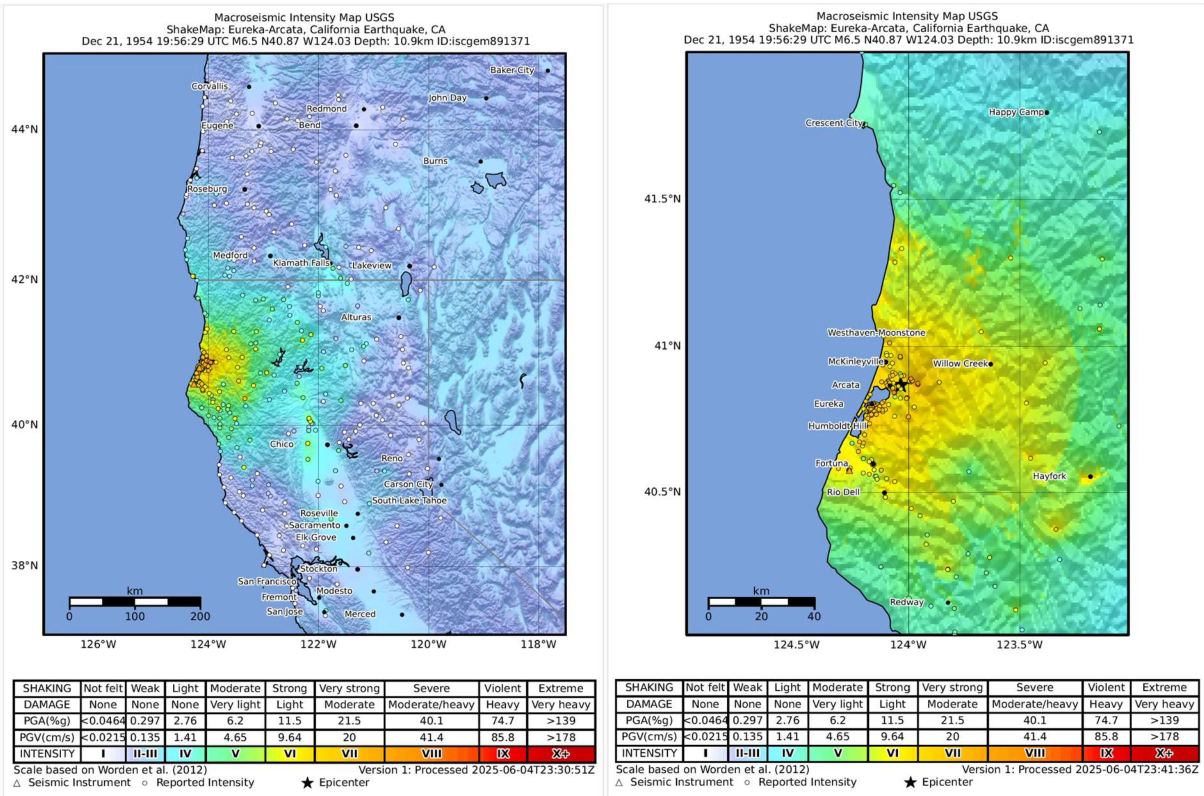


Figure 8: Regional (left) and zoomed in (right) reevaluated shaking intensity for the 1954 Fickle Hill earthquake (Hough et al., 2025) using the current ShakeMap approach based on ground motion models and site response terms (Worden *et al.,* 2020).

Table 1: Phase arrivals including polarities and source information for the polarity of the P-phases

Station	Phase	Abs. Time*	Arrival Time	Uncert† (s)	Prior Wt‡	Pred TT§ (s)	resid$^{\Vert}$ (s)	Post Wt$^{\#}$	Distance (km)	Azi-muth (deg)	P-Polarity MS			P-Polarity AS			Polarity Source
											V	N	E	V	N	E	
ARC	P	Y	19:56:31.7	1.0	1	2.5	0.1	1.8	3.9	285	+	-	-		-	-	V inferred, N&E record
ARC	S	N	19:56:34.2	2.0	0	4.5	0.6	0.0	3.9	285							
EUR	P	N	19:56:33.0	1.0	1	3.6	0.5	0.2	13.4	236							
EUR	S	N	19:56:36.3	2.0	1	6.5	0.0	0.1	13.4	236							
FER	P	Y	19:56:39.0	1.0	1	7.6	0.6	0.1	37.9	211	+	-	-				V inferred, N&E reading
FER	S	N	19:56:45.5	2.0	1	13.5	0.0	0.1	37.9	211							
SHS	P	Y	19:56:50.4	1.0	1	21.3	0.1	1.5	139.9	97	+						Reading sheet
SHS	S	Y	19:57:07.6	2.0	1	38.0	0.5	1.2	139.9	97							
UKI	P	Y	19:56:58.0	1.0	1	29.4	-0.5	1.4	205.1	160							
UKI	S	Y	19:57:16.0	1.0	1	52.4	-5.5	0.2	205.1	160							
MIN	P	Y	19:56:59.5	1.0	1	30.9	-0.5	1.4	213.3	105	+	+	+				V inferred S&E reading sheet
MIN	S	Y	19:57:24.0	2.0	1	55.0	-0.1	1.2	213.3	105							
BRK	P	Y	19:57:18.4	1.0	1	49.6	-0.3	1.4	366.6	155	+	-	+				records
BRK	S	Y	19:57:59.7	2.0	1	88.3	2.3	0.8	366.6	155							
REN	P	Y	19:57:22.7	1.0	1	52.7	0.9	1.3	387.9	111	+	-	+	-	+	+	records

PAC	P	Y	19:57:24.6	1.0	1	55.8	-0.3	1.4	416.1	157	+	-	+				records
PAC	S	Y	19:58:08.0	2.0	1	99.3	-0.4	1.0	416.1	157							
COR	P	Y	19:57:26.0	1.0	1	56.1	0.8	1.3	418.1	8				+		-	records
COR	S	Y	19:58:07.8	2.0	1	99.8	-1.1	1.0	418.1	8							
MHC	P	Y	19:57:28.4	1.0	1	59.6	-0.3	1.4	443.5	151	+	+	+	+			records
MHC	S	Y	19:58:15.3	2.0	1	106.1	0.1	1.0	443.5	151							
FRE	P	Y	19:57:47.1	1.0	1	77.0	1.0	1.2	585.7	140	+	+	+	+	+	+	records
TIN	P	Y	19:57:50.0	1.0	1	86.3	-5.4	0.3	657.4	128							
KRC	P	Y	19:58:03.2	1.0	1	94.2	-0.1	1.2	722.0	147							
WDY	P	Y	19:58:03.4	1.0	1	95.4	-1.1	1.1	732.2	140							
HAI	P	Y	19:58:08.0	1.0	1	97.5	1.4	1.1	746.9	133							
ISA	P	Y	19:58:08.5	1.0	1	98.5	0.9	1.1	755.8	138							
FTC	P	Y	19:58:13.9	1.0	1	104.7	0.1	1.2	805.3	144							
SBC	P	Y	19:58:15.5	1.0	1	105.1	1.3	1.1	810.1	150							

*Abs Time: Absolute time - whether the arrival time is directly from picks on the record or inferred (see text).
†Uncert: Assigned uncertainty at the beginning of analysis.
‡Prior Wt: Assigned weight at the beginning of analysis.
§Pred TT: Travel time predicted for the most likely location.
‖Resid: Residual between measured arrival and predicted arrival times.
#Post Wt: Weight assigned by the algorithm for the most likely solution.

Table 2: Smooth velocity model derived from (Henstock and Levander, 2003) and the MEN2 model from (Oppenheimer et al., 1993)

Top depth (km)	Vp (km/s)	Vp gradient ((km/s)/km)	Vs (km/s)	Vs gradient ((km/s)/km)
-5.00	2.92	0.000	1.64	0.000
0.00	2.92	0.422	1.64	0.237
4.10	4.64	0.238	2.61	0.133
10.00	6.05	0.095	3.40	0.053
20.00	7.00	0.333	3.93	0.187
23.00	8.00	0.000	4.49	0.000

Table 3: Best locations at test depths

Direction from ARC	Latitude	Longitude	Depth (km)	Horizontal Uncertainty (km)
SE	40.853	-123.953	1.6	9.4
SE	40.857	-123.966	3.6	7.4
SE	40.858	-123.982	5.6	7.7
SE	40.861	-124.005	8.1	7.1
SE	40.865	-124.036	11	7.6
SE	40.870	-124.064	14	7.1
SW	40.875	-124.094	18	7.6
SW	40.875	-124.112	21	8.4
SW	40.875	-124.116	24	8.1

SW	40.873	-124.116	27	8.8
SW	40.870	-124.112	30	8.4
NE	40.888	-124.040	11	n/a
NE	40.882	-124.065	14	n/a

Supplemental Information

Figure S1: Alternate possible mechanisms with waveform fits.

Figure S2: Comparative plot of velocity models discussed in the text.

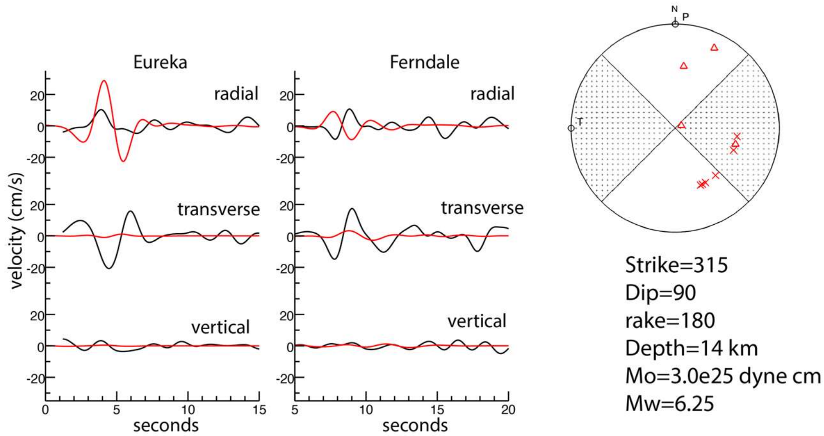
Table S1: Hypocentral locations for the 21 December 1954 earthquake given in the literature.

Table S2: Station information.

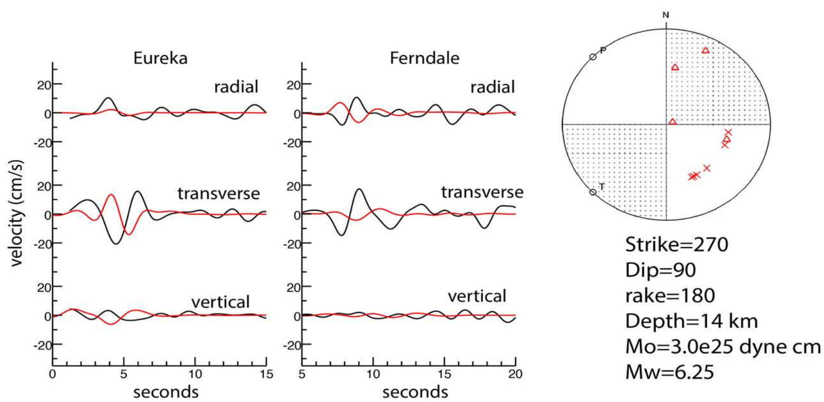
Appendix S1: Eyewitness accounts and the corresponding intensity.

Appendix S2: Contents of the assembled dataset at the Northern California Earthquake Data Center (ncedc.org).

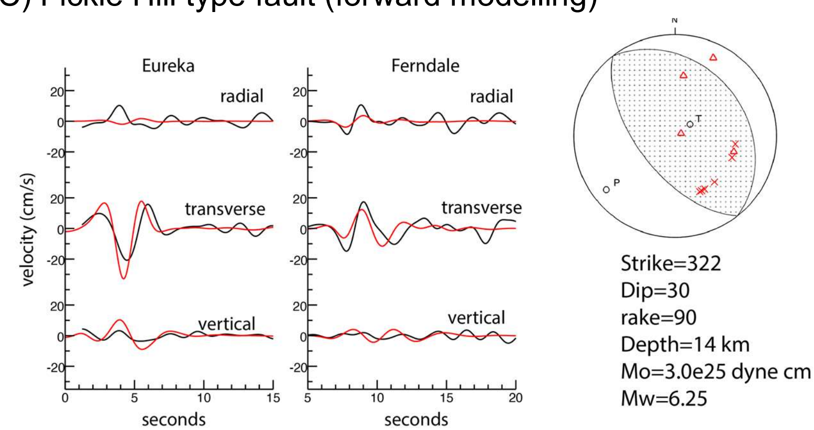
(A) Gorda Intraplate type fault (forward modelling)



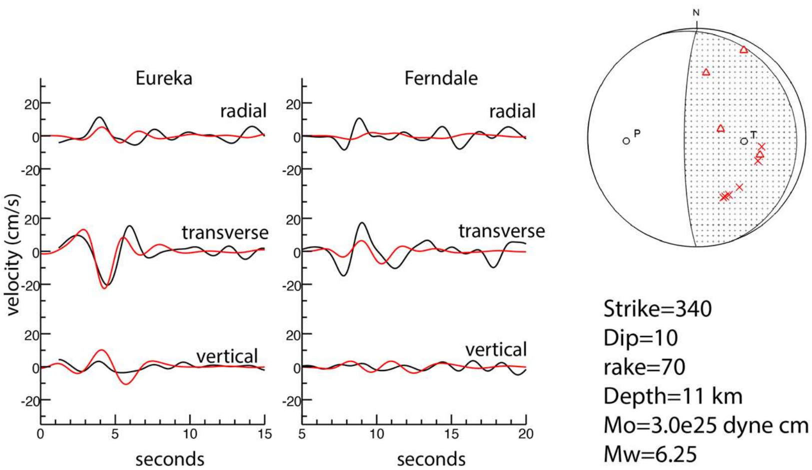
(B) Mendocino type fault (forward modelling)



(C) Fickle Hill type fault (forward modelling)



(D) Alternate NE location, 11 km depth



(E) Hypocenter SW of ARC, 18 km depth

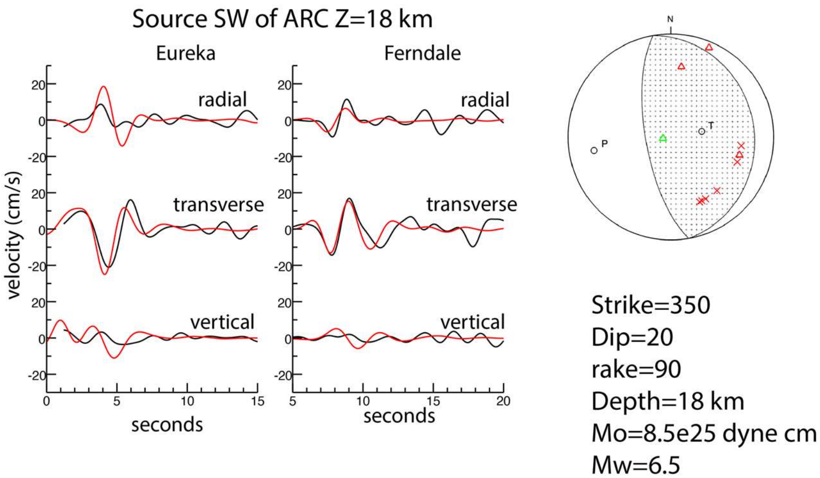


Figure S1. Observed (black) and synthetic (red) waveforms and first motion observations for hypothetical earthquake mechanisms. Forward modelling solutions for (A) an intraplate Gorda event, (B) an event on a Mendocino fault oriented rupture plane and (C) an event on the Fickle Hill or one of its sister faults. These mechanisms all violate both the waveforms at Eureka and Ferndale and the distribution of first-motion polarity, with only the Ferndale polarity inconsistent for the Fickle Hill test. (D) "Best-fit" mechanism for a location at a slightly shallower depth location (11 km) for a source to the NE of ARC. (E) Mechanism and fit for a source to the SW of ARC at 18 km depth. Note the negative polarity (green triangle) for ARC for this hypocenter which does not fit the mechanism. Solutions in (D) and (E) are from fitting both the waveforms and the polarities. For the mechanism plots, red symbols denote up first motion and green down. X shows polarities directly observed on vertical components, whereas triangles show polarities inferred from observations of the two horizontal P-wave polarities.

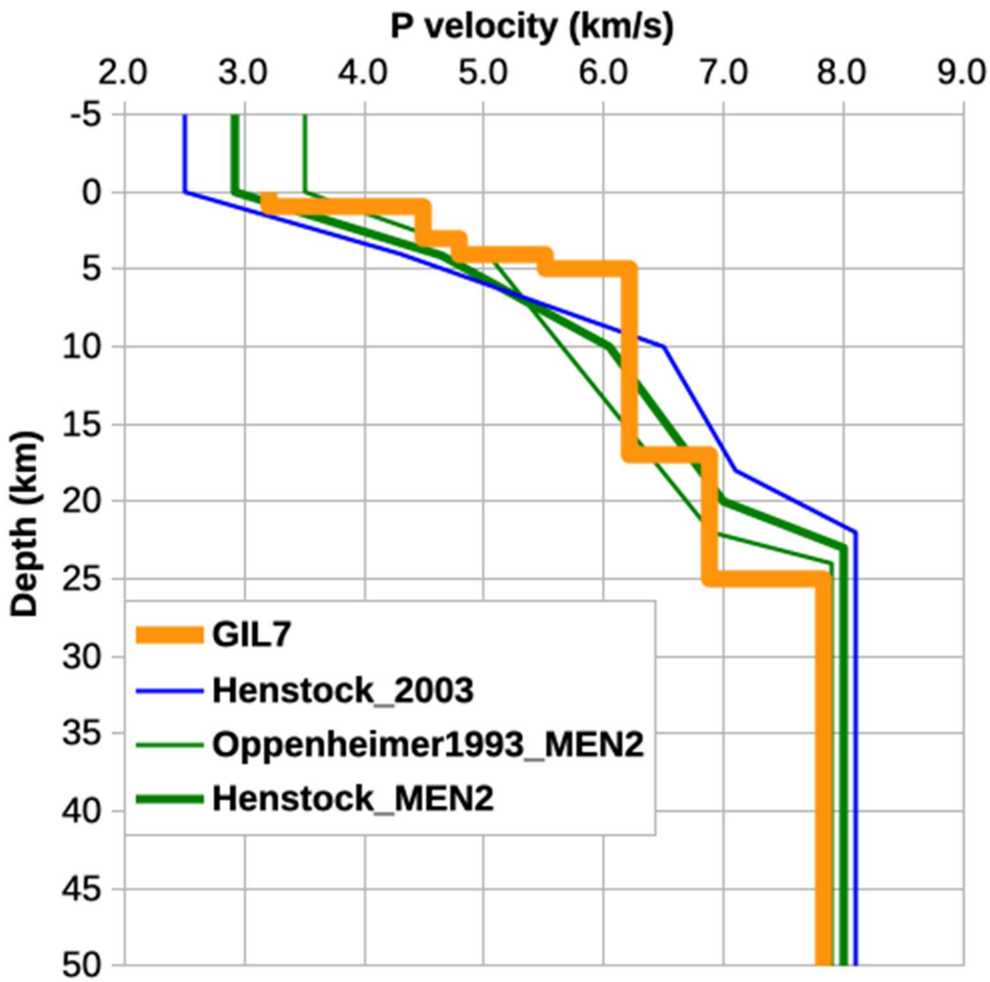


Figure S2. Comparative plot of the velocity models referred to in the text.

Supplemental Table S1: Hypocentral Locations from the Literature.

Source	Origin time	Lat	Long	Depth	Magnitude	Number Key	References
USCGS-ISC	19:56:27.50	40.490	-123.050			1	"ISC (2025), event ID 891371"
TERA-NEIS		40.780	-123.790			2	Smith & Knapp (1977)
Bolt-Miller	19:56:29	40.780	-123.870		6.5	3	Bolt & Miller (1975)
BSS	19:56:29.00	40.783	-123.867		M 6.5 UCB	4	Milne (1957)
Comcat	19:57:24.00	40.783	-124.167			5	USGS (2017)
NEIC-USHIS	19:55:24.40	40.783	-124.167		M 6.5 UCB	6	USGS (2017)
USCGS-3		40.783	-124.083			7	Murphy & Cloud (1984)
Tocher		40.817	-124.083			8	Tocher (1956a)
USCGS-4	19:56:27.00	40.783	-123.083			9	Murphy & Cloud (1984)
USCGS-2	19:56:29.00	40.817	-124.083			10	Murphy & Cloud (1984)
ISC-CAT	19:56:30.00	40.846	-123.893	15	M 6.6 PAS	11	ISC (2025) Event 891371
TERA		40.850	-123.960	12		12	Smith & Knapp (1977)
USCGS-1		40.867	-123.883			13	UCB reading sheet comment: letter from USCGS director 2/18/1955 cites this location
ISS	19:56:25.00	40.900	-123.800			14	ISC (2025) Event 891371
Cameron	19:56:28.00	40.900	-123.917	12.2		15	Cameron (1961a)
TERA-Iso		40.900	-124.000			16	Smith & Knapp (1977)
TERA-SK		40.940	-124.000			17	Smith & Knapp (1977)

Supplemental Table S2: Station Information on the stations' locations, the equipment operating at the time (Bolt and Miller, 1975) and whether the records were found and scanned.

Station Code	Operator	Lat	Long	Elev (m)	Orientation	Instrument	MS Record	AS Record	Location
ARC	BSS	40.878	-124.077	30	NS	WA	S	S	Arcata (Humboldt State Col.), CA
ARC	BSS	40.878	-124.077	30	EW	WA	S	S	Arcata (Humboldt State Col.), CA
EUR	USCGS	40.801	-124.164	5	V	ACC	dig		Eureka (Federal Bldg), CA (now Post Office)
EUR	USCGS	40.801	-124.164	5	349	ACC	dig		Eureka (Federal Bldg), CA (now Post Office)
EUR	USCGS	40.801	-124.164	5	79	ACC	dig		Eureka (Federal Bldg), CA (now Post Office)
FER	BSS	40.576	-124.264	16	NS	BO	S	S	Ferndale (City Hall), CA
FER	BSS	40.576	-124.264	16	EW	BO	S	S	Ferndale (City Hall), CA
FER	USCGS	40.576	-124.264	16	V	ACC	dig		Ferndale (City Hall), CA
FER	USCGS	40.576	-124.264	16	44	ACC	dig		Ferndale (City Hall), CA
FER	USCGS	40.576	-124.264	16	314	ACC	dig		Ferndale (City Hall), CA
SHS	BSS	40.695	-122.388	312	V	BEN	film		Shasta, CA
SHS	BSS	40.695	-122.388	312	NS	BEN	film		Shasta, CA
SHS	BSS	40.695	-122.388	312	EW	BEN	film		Shasta, CA
UKI	USCGS	39.137	-123.211	199	??	??			Ukiah (Intl. Latitude Obs.), CA
MIN	BSS	40.345	-121.605	1495	V	BEN	S		Mineral, CA
MIN	BSS	40.345	-121.605	1495	SN	WA	S		Mineral, CA
MIN	BSS	40.345	-121.605	1495	EW	WA	S		Mineral, CA

BRK	BSS	37.874	-122.261	49	V	GAL	S		Berkeley (Haviland), CA
BRK	BSS	37.874	-122.261	49	NS	GAL	S	S	Berkeley (Haviland), CA
BRK	BSS	37.874	-122.261	49	EW	GAL	S	S	Berkeley (Haviland), CA
BRK	BSS	37.874	-122.261	49	V	BEN	S		Berkeley (Haviland), CA
BRK	BSS	37.874	-122.261	49	NS	BO	S		Berkeley (Haviland), CA
BRK	BSS	37.874	-122.261	49	EW	BO	S		Berkeley (Haviland), CA
REN	BSS	39.539	-119.814	1386	V	SP	S		Reno (University of Nevada), NV
REN	BSS	39.539	-119.814	1386	NS	SP	S		Reno (University of Nevada), NV
REN	BSS	39.539	-119.814	1386	EW	SP	S		Reno (University of Nevada), NV
PAC	BSS	37.417	-122.182	83	V	BEN	S		Palo Alto (Stanford), CA
PAC	BSS	37.417	-122.182	83	NS	WA	S		Palo Alto (Stanford), CA
PAC	BSS	37.417	-122.182	83	EW	WA	S		Palo Alto (Stanford), CA
COR	BSS	44.586	-123.303	121	V	SL		S	Corvallis (Oregon State Univ.), OR
COR	BSS	44.586	-123.303	121	NS	SL			Corvallis (Oregon State Univ.), OR
COR	BSS	44.586	-123.303	121	EW	SL		S	Corvallis (Oregon State Univ.), OR
MHC	BSS	37.342	-121.642	1282	V	BEN	S	S	Mount Hamilton, CA
MHC	BSS	37.342	-121.642	1282	NS	WA	S	S	Mount Hamilton, CA
MHC	BSS	37.342	-121.642	1282	EW	WA	S	S	Mount Hamilton, CA
FRE	BSS	36.768	-119.797	88	V	SP	S		Fresno (City College), CA
FRE	BSS	36.768	-119.797	88	NS	SP	S		Fresno (City College), CA
FRE	BSS	36.768	-	88	EW	SP	S		Fresno (City College), CA

			119.797							
TIN	CSL	37.054	-118.230	1164	??					Tinemaha Reservoir, CA
KRC	CSL	35.327	-119.745	680	??					King Ranch Kern County, CA
WDY	CSL	35.700	-118.844	457	??					Woody, CA
HAI	CSL	36.137	-117.948	1110	??					Haiwee, CA
ISA	CSL	35.663	-118.47	873	??					Lake Isabella, CA
FTC	CSL	34.872	-118.900	990	??					Fort Tejon, CA

ACC=USCGS accelerometer (Cloud, 1965); BEN=Benioff seismograph (Benioff, 1932); BO=Bosch-Omori seismograph(Shea, 1955); GAL=Galitzin seismograph (Galitzin, 1910); SL=Slichter seismograph (Slichter, 1936); SP=short period Sprengnether seismograph (Sprengnether, 1947); WA =Wood-Anderson seismograph (Anderson & Wood, 1925)

Supplemental Table S3: Supporting intensity information collected from eyewitness accounts and other sources.

Report No.	Person	Description	Place	Location	Report	min MMI	date	Contact type
1	Anne Pierson	age 11 riding bike	Eureka	40.786, -124.152	couldn't ride bike, chimneys down, power lines arcing, heavy furniture toppled	7	Jul-24	PI
2	Jennifer Davis Godwin	inside	Eureka	40.79, -124.17	chimney down, ground roll	7	Nov-24	FB
3	Steve Rosenberg	inside	Eureka	40.789, -124.154	slid across room in chair, chimneys down	7		FB
4	Roger Smith	age 8 outside	Arcata	40.92, -124.076	fell down, heavy bookcase fell	7	Nov-24	FB
			Arcata/HSU	40.88, -124.077	books fell in an E-W direction	6		
			Arcata/Plaza	40.87, -124.09	many items toppled/broken	6		
5	Derral Alexander Campbell	indoors - preschooler	Eureka	40.78, -124.178	xmas tree bouncing, got under a table	5		
6	Kerry Joanie Griffith	inside	Eureka	unspecified	oven door flew open, chimney toppled	7	Nov-24	FB
7	Greg Barnes		Fortuna	40.596, -124.156	Lots of buidling debris in street	6	Nov-24	FB
8	Barb Harper		Eureka	40.794, -124.165			Aug-24	PI
		inside	Cutten	40.769, - 124.143	ground roll, water splashed out of washing machine	7	Sep-24	
		outside	Eureka	40.764, -124.166	adult thrown to grown,thought it was a bomb, power lines down	7	Sep-24	
			Cutten	40.764, -124.149	many items toppled/broken	6	Sep-24	
9	Linda Barellis	inside age 9.5	Eureka	40.784, -124.168	telephone poles swaying, items toppling	6	Sep-24	PM
10	Penelope Chastaine	inside age 11	Eureka	40.800, -124.151	Chimney down, items toppled, outside objects swaying	7	Sep-24	PM
11	John Nicholas	inside age 4	Eureka	40.794, -124.172	loud noises, dishes falling off shelves, family found it hard to stand	7	Sep-24	PM
12	Roxie Paxton	outside age 9.5	Rohnerville	40.576, -124.121	ground roll, bricks and shingles fell from roof	7	Sep-24	PM
13	Rowetta Miller	inside	Showers Pass	40.587, -123.83	Uncle on roof could barely hang on, strongest they had felt	7	Aug-24	TS
14	Susie Baker Fountain	outside	Mad River	unspecified	fishermen reported water flowing upstream, child thrown to floor and nearby adult thrown against wall		1954	SBFP
15	Holmes Eureka Lumber Company	outside	Korbel	40.876, -123.958	employee thrown into log pond and drowned	8	1954	
16	Joline Bettendorf	inside	Arcata	40.876,-124.055	door slammed, many items off shelves	7	Aug-24	TS
17	Kay Escarda	inside	McKinleyville	40.968,-124.107	in shower, lights out, many items fell	7	Aug-24	TS
		inside	Arcata	40.874,-124.095	ground roll, heavy furniture displaced, cows outside navigating rolling ground	7		

18	Jack Nash	inside	Eureka	40.80,-124.166	plate glass windows broken, much debris in store and street	7	Dec-24	TS
19	Jane Carlton	inside - mother was 14	Warren Creek	40.895,-124.042	ground roll, heavy water line tossed from supports	8	Sep-24	PI
20	Rod Ledbetter	inside age 4	Arcata Bottoms	40.902,-124.096	watched a cup vibrate across a counter and not fall	5	Oct-24	PI
21	Judith St. Clair	inside uncle's story	Arcata	40.87,-124.091	Post office damaged so that door was wedged shut	7	Jul-24	PI
22	Daughter of Holmes Lumber Co. employee	inside, father's story	Korbel	40.873,--123.96	Thown in desk chair across room		Jan-92	PI

Contact Type Abbreviations
TS - responses to Times-Standard article 7/27/24
PI – Personal interviews
FB - Responses to a query in the Humboldt County History Facebook Page
SBFP - Journal entries in the Susie Baker Fountain Papers from the Cal Poly Humboldt Library

Appendix S1: Recently collected eyewitness accounts and the corresponding intensity.

Intensity reports of the 1954 Fickle Hill Earthquake

The table below summarize felt reports gathered as part of this study. The majority are the results from requests for accounts in the last year in publications like the regional newspaper Times-Standard and Senior News. Additional responses came from the Humboldt County History and Humboldt County on Alert Facebook pages. A few were from the Susie Baker Fountain Papers, an archive of clippings, memorabilia, and regional history from 1850 to 1966. The papers are archived at Cal Poly Humboldt (https://specialcollections.humboldt.edu/susie-baker-fountain-papers). One report came from 1992 at a community meeting.

Most of the reports are the recollections of children from age 3 to early teens and as such should be considered highly selective. Memories of 65 or more years ago from a child will not encompass a complete assessment of impacts. The table estimates minimum intensities. Intensities above 7 are based primarily on structural damage and other than wide-spread reports of chimneys toppling, these children did not remember what happened to building foundations or other structures.

One of the most prevalent memories is seeing the ground undulate. Ground roll was mentioned by most who were outside at the time of the earthquake and by a few who were indoors. “Waves are seen on ground surfaces” is included in XII (Extreme) in the Modified Mercalli Scale but is not included in the USGS “Did You Feel It?” questionnaire and has been poorly studied as an indicator of shaking strength. Ground roll reports from more recent earthquakes including 1989 Loma Prieta and 1992 Cape Mendocino are in areas mapped from MMI VII to IX from other methods.

Intensity Reports gathered for this study

#	Respondent	Age	Location	~ Lat/Lon	Description	MMI*	date	source
1	Anne Pierson	age 11 riding bike	Eureka	40.786, -124.152	couldn't ride bike, chimneys down, power lines arcing, heavy furniture toppled	7	Jul-24	PI
2	Jennifer Davis Godwin	inside	Eureka	40.79, -124.17	chimney down, ground roll	7	Nov-24	FB
3	Steve Rosenberg	inside	Eureka	40.789, -124.154	slid across room in chair, chimneys down	7		FB
4	Roger Smith	age 8 outside	Arcata	40.92, -124.076	fell down, heavy bookcase fell	7	Nov-24	FB
			Arcata/HSU	40.88, -124.077	books fell in an E-W direction	6		
			Arcata/Plaza	40.87, -124.09	many items topled/broken	6		
5	Derral Campbell	indoors	Eureka	40.78, -124.178	xmas tree bouncing, got under a table	5		
6	Kerry Joanie Griffith	inside	Eureka	unspecified	oven door flew open, chimney toppled	7	Nov-24	FB
7	Greg Barnes		Fortuna	40.596, -124.156	Lots of buidling debris in street	6	Nov-24	FB
8	Barb Harper		Eureka	40.794, -124.165			Aug-24	PI

		inside	Cutten	40.769, -124.143	ground roll, water splashed out of washingmachine	7	Sep-24	
		outside	Eureka	40.764, -124.166	adult thrown to grown,thought it was a bomb, power lines down	7	Sep-24	
			Cutten	40.764, -124.149	many items toppled/broken	6	Sep-24	
9	Linda Barellis	inside age 9.5	Eureka	40.784, -124.168	telephone poles swaying, items toppling	6	Sep-24	PM
10	Penelope Chastaine	inside age 11	Eureka	40.800, -124.151	Chimney down, items toppled, outside objects swaying	7	Sep-24	PM
11	John Nicholas	inside age 4	Eureka	40.794, -124.172	loud noises, dishes falling off shelve, family found it hard to stand	7	Sep-24	PM
12	Roxie Paxton	outside age 9.5	Rhonerville	40.576, -124.121	ground roll, bricks and shingles fell from roof	7	Sep-24	PM
13	Rowetta Miller	inside	Showers Pass	40.587, -123.83	Uncle on roof could barely hang on, strongest they had felt	7	Aug-24	TS
14	Susie Baker Fountain	outside	Mad River		fishermen reported water flowing upstream, child thrown to floor and nearby adult thrown against wall		1954	SBFP
15	Holmes Eureka Lumber Comapan	outside	Korbel	40.876, -123.958	employeed thrown into log pond and drowned	8	1954	SBFP
16	Joline Bettendorf	inside	Arcata	40.876,-124.055	door slammed, many items off shelves	7	Aug-24	TS
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19	Phyllis Carlton	inside - mother was 14	Warren Creek	40.895,-124.042	ground roll, heavy water lione tossed from supports	8	Sep-24	PI
20	Rod Ledbetter	inside age 4	Arcata Bottom	40.902,-124.096	watched a cup vibrate across a counter and not fall	5	Oct-24	PI
21	Judith St. Clair	inside uncle's story	Arcata	40.87,-124.091	Post office dmaged so that door was wedged shut	7	Jul-24	PI
22	Daughter of Holmes Lumber Co. employee	inside, father's store	Kobel	40.873,--123.96	Thown in desk chair across room		Jan-92	PI
23	Margot Genger	inside 3rd floor	Eureka	40.799, -124.16	Water sloshed out of bathtub, mother couldn't move, chimney damaged	7	25-Jun	PI
24	Margot Genger (account from her brothers	outside, walking	Eureka	40.80, -124.16	ground roll, knocked a man to the ground	7+	25-Jun	PI

* MMI estimates are minumums

Source abreviations:

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Report	Respondent	Complete description
1	Anne Pierson age 11	Eleven year-old Anne Pierson was riding her bicycle with a friend on Buhne Street in Eureka heading west between L and N when suddenly it became impossible to ride their bikes. Her friend immediately dropped to the ground and covered her head as they had been taught in school for atomic bomb drills. Anne immediately recognized it as an earthquake and watched what was happening around her. She saw the ground roll across the street coming from the north and heading south, electric lines and poles shaking wildly, and sparks flying. She saw several chimneys topple from houses to the west on Buhne Street. One woman whose chimney toppled came running out of her house – Anne laughed because the woman's hair was in curlers. She didn't feel frightened and once the shaking was over, they got back on their bikes and headed to H and 15th where they delivered Christmas presents. At that house, everything on the second floor had come off shelves and lots of knickknacks were broken, including a large cabinet toppling over. Her recollection was the shaking wasn't as strong as what she experienced in the second-floor bedroom of her home in Freshwater on December 20, 2022. But the experience of being 11 on a bicycle outside is very different than being awoken from a sound sleep indoors. She also remembers the streets so jammed with cars of people trying to drive home from work that it was hard to cross the road.
2	Jennifer Davis Godwin	My friend Linda Stromberg and I were sitting in the living room of my parents' three story, 1912 house on E Street when it hit. We were making paper chains for the Christmas tree. A huge roar and the shaking began. I recall seeing E Street rolling as we jumped up, terrified. There was a loud crash outside where the top of the chimney came down. The house had curved glass in the turret windows which shattered. Dad had to order new ones from San Francisco which took a while to get shipped. Lamps were lost but the Christmas tree stayed upright. My mom ran outside and we joined her. My stepbrother brought my sister downstairs to join us. I remember Mom being terrified, and goodness, the noise!
3	Steve Rosenberg	I was sitting at my desk about five feet away from the window of my upstairs bedroom on O street in Eureka near Albee stadium The sky was gray. It was dead calm. The quake struck with tremendous noise. I hung on to my desk and it and me in my chair started sliding south towards the window. I turned to look outside and the neighbors house was waving back and forth like a flag. When the shaking stopped ,i was almost against the window. I ran downstairs and went out in the street. Dogs were wailing all around. My friend Larry Doyle and his father Ed appeared and we went around the houses checking for damage. All of a sudden we heard another big roar and an aftershock hit. The trees were waving. Quite an experience for an eight year old. The courthouse and high school had terminal damage. The catholic church steeple failed. Lots of broken chimneys. But the 1992 and 2022 were worse, at least near college of the redwoods where I live, as they were centered further south. 2010 was bad too. It was just southwest at the eel river canyon.It was exciting for me as a child. Now they are dreadful .
4	Roger Smith age 8	My older cousin was cutting brush with a brush hook so the road access was better, dad was trying to square up the pump house because PG&E pulled it off plumb when hooking up the power lines, I was playing on the dirt pile created from digging the well. My cousin let the brush hook fly out of his hands (We never found it), dad yelled out "Ralph with the hell are you doing out there", and I fell to my knees. We went up the hill to our "house", a 20' x 24' cabin that, at the time had no electricity or water). Discovered that a glass dish had fallen and broken on top of the meat that was supposed to be dinner. We then got into the car and went to the HSC campus, as dad was the Chemistry Professor. He was really worried about the "stock room". Found very little damage, a couple of glass items had hit the floor but nothing serious. My mind thinks the shelves were in a north south configuration. This was in the "basement" of Founders Hall. Now the "New Library", presently the Engerniring Building (?) north of Founders Hall had almost all of the books on the floor. It seems that their shelves were in an east west configuration. We then went down to the plaza where Brizards grocery store was sweeping lots of glass and product out into the street. We needed to get something out of the freezer locker to thaw out for dinner. I also remember my folks talking about a store that had "earthquake wires" on their hard liquor. Hutchens, Arcata Liquors, I don't remember the exact store, and it might have been an on/off sale bar. I also remember a floor to cieling book case that crashed to the floor in our house that crashed down and broke the coffee table. On the very top shelf is where dad had the .22 stored. The butt plate was broken. To this day that .22 still has a broken butt plate and I still own it. I also have

		memories of the flood the following year, or was it the previous year. I'd be very happy to share more memories just reply.
4	Roger Smith	My older cousin was cutting brush with a brush hook so the road access was better, dad was trying to square up the pump house because PG&E pulled it off plumb when hooking up the power lines, I was playing on the dirt pile created from digging the well. My cousin let the brush hook fly out of his hands (We never found it), dad yelled out "Ralph with the hell are you doing out there", and I fell to my knees. We went up the hill to our "house", a 20' x 24' cabin that, at the time had no electricity or water). The house was at the top of Azalea Hill. Go up to the top, coming off North Bank Road, take a right on Hewitt Road, there are two roads, the one to the south is Sunnygrove, to the north is Hewett Presently there is a mobile home park there, but the little house that we were living in is still there, at least the last time I was there about 10 years ago. Discovered that a glass dish had fallen and broken on top of the meat that was supposed to be dinner.
4	Roger Smith	-We then got into the car and went to the HSC campus, as dad was the Chemistry Professor. He was really worried about the "stock room". Found very little damage, a couple of glass items had hit the floor but nothing serious. My mind thinks the shelves were in a north south configuration. This was in the "basement" of Founders Hall. Now the "New Library", presently the Engerniring Building (?) north of Founders Hall had almost all of the books on the floor. It seems that their shelves were in an east west configuration.
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5	Derral Alexander Campbell	In the '54 shaker, i was at the Child Care Center, next to Marine View Terrace school in west Eureka. I remember the Christmas tree bouncing and swaying, and getting under a desk or table.
6	Kerry Joanie Griffith	the cookies flew out of the oven and the brick chimney on our old Victorian tumbled off the roof!!
7	Greg Barnes	I lived in Fortuna at the time of that quake on 11th street. It was a rather strong quake…lots of bits and pieces of buildings in the streets.
8	Barb Harper	I was with my mom and brother and we were visiting a friend who lived in Eureka on E street between 13th and 14th streets My brother and I were playing in the playground across the street when the earthquake struck we were very scared and ran to our mother who was in the two story apartment when another jolt came while we were in the stairwell of the apartment.
8	Barb Harper	I talked to my 95 year old aunt who lived in Cutten on Walnut Drive across from where the Humboldt C.S.D. Is today and she remembers it very well. She said that it was very scary, she saw the earth raising up and down in waves. The water splashed out of her wringer washing machine. She said that her boys were playing in the woods across the street where the HCSD is today and she ran as fast as she could to get to them.

8	Barb Harper	My Sister in law remembers it the same as my late husband who lived on D street in Eureka near the community golf course.Their dad was home for lunch (he worked for PG&E) and asked my future husband to fetch his toolbox from his truck. The earthquake struck as he was carrying it down the driveway and the earthquake threw him to the ground and my father in law thought that was a bomb since he was a sailor during the war. He went down the street turning off gas lines and found power lines down at Alder and D streets and stood guard until more help arrived to turn off the power. Their Christmas tree toppled over breaking many of their ornaments. They put eye screws in the corner of the living room and had their Christmas trees secured forever after.
8	Barb Harper	Mom took us to our home at Excelsior and Holly streets in Cutten to find a lot of things broken.
9	Linda Barellis	Was 9.5 yr old and on 2nd story of Saint Bernards, lots of shaking and some items toppling; father near 6th & F st and saw telephone poles swaying
10	Penelope Chastaine	Was 11 years old watchings 8 yr and 4 yr old brothers while mom at grocery store; remembers seeing 8 yr old on slide in backyard swaying back and forth a lot (he had fun) and 4 yr old was put to the ground and had to crawl to sister in the doorway; broken chimney, christmas tree knocked over and ornaments shattered; shelf with teacups fell and all broke; lived at 930 S St Eureka
11	John Nicholas	Was 4 years old and he remembers the dishes shaking off shelves, his family members were hanging onto the walls, there were lots of loud sounds and lots of items falling; home located at 1461 California St, Eureka
12	Roxie Patton	I was 9 years old at the time and living on Rohnerville Road, Rohnerville, (now Fortuna, Ca) when the earthquake hit. It was a nice day out and my mother Luva Wendt was mowing the lawn with a push mower. I was outside playing and the lawn started moving like waves and I tried running towards her and jumping over these mounds. It seemed to last forever. During this time my grandfather was outside (grandparents lived next door) and my grandmother ran to backdoor and tried to exit when my grandpa yelled at her to stay in. He was right as just at that moment bricks and shingles started falling off the roof right at the doorway and she would have probably been hurt
13	Rowetta Miller	In response to your inquiry in the Sunday July 28, 2024 Times Standard concerning the location of the 1954 M 6.5 earthquake, I was living with my family on our Bootjack homestead in the mountains of Showers Pass. Our Great Uncle Dee who lived with us at the time, was repairing shakes on the roof of the laundry room attached to the original homestead cabin. This is also where he slept and I guess he preferred not to get wet in his sleep. It was the strongest earthquake we had felt in that area. Uncle Dee had to hold on tight to prevent from falling off the roof. I was attending Heart's Valley School and in sixth grade at the time. I recall being home so I'm unsure of the day of the week when the earthquake jolted my Uncle Dee on the roof. We were all relieved that he didn't fall off. Our location was across the Mad River and approximately four miles up the hill on the south side of Mad River where Deer Creek enters the Mad on the north. Bug Creek and Humbug Creek also enter the Mad on the north side of Mad River -- several miles downriver from our homestead.
14	Susie Baker Fountain	Fisherman "thrown off balance into the stream." SF1954: "Suddenly, the river flopped back against him, knocking him flat."
15	Holmes Eureka Lumber Comapan	Employee "reportedly hurled into a log pond by the impact of the quake," and drowned.
16	Joline Bettendorf	Working at Whirligig Restaurant while attending Humboldt. It was located on G Street between Tatman's Bakery and the grocery store in North Arcata. One memorable event was the 6.5 earthquake on December 21, 1954. Newspapers had been full of forecasts of a quake on that date. I sniffed. "Earthquakes can't be that precisely forecast." On the twenty-first I was the cook on duty when the quake struck. I was in the store room, an enclosed room past the counter and grill with shelves full of cans and bottles. The door slammed shut in the shaking . Goods cascaded from the shelves around me in the total dark. When the shaking stopped, I found the door, tore into the restaurant and screamed, "My God, it's the twenty-first." Still holding out at the counter were three men who looked at me blankly, as if I had lost my mind.They must have beenwondering why in the world I was screaming the date after surviving The Big Shake."

17	Kay Escarda	About seven miles north at the airport apartments, located alongside the fence separating the public area from the airport restricted areas, where the terminal is now located, my mother was taking a shower. The apartments were former officer quarters. Ours was on the second floor, built on a slope with the elevation facing west toward the ocean. The bathroom was interior with no windows or light source. When the quake struck, she said the lights went out and in total darkness, she grabbed the faucet handles, gave herself a blast of cold and then a blast of hot and slithered out onto the cold floor. There was quite a mess of fallen items, things dumped from cupboards but no real household damage. I also worked cleaning house for an employee of HSC. She lived in a duplex on west 13th Street near the Arcata Methodist Church. She and her young son were both home sick with the flu. I had made chicken soup and was just starting to spoon some into bowls for them when the quake struck. The pot flew out of my hands onto the floor, the west cupboards flew open and all the dishes came crashing out. Johnny screamed and I lurched down the hall toward his bedroom as we continued to rock and roll. I looked out the bedroom window northward and will never forget the sight of cows from the dairy across the street running across the field. The land was rolling like ocean waves which seemed about twenty feet deep. The cows looked like camels, all distorted with their haunches several feet above their heads as they all staggered to the east in one mass. A huge dresser mirror barely missed Johnny's head and the Christmas tree in the living room made another crashing sound. I spent the rest of the day cleaning up the mess, made them a light dinner late in the evening and went back to help my sister clean up the mess at our own apartment.
18	Jack Nash	My story is that I was a regular customer at Jim's Barber Shop at 511 Henderson Street in Henderson Center, Eureka. It was later called the Barber Center and owned for many years by Al Sanders. It is still a barber shop. I was not in the barber chair when the quake hit but in one of the "waiting" chairs. The quake scared me so much I hopped on my bicycle and rode home to 1915 "D" Street to find my mom cleaning up all the broken glass jars in the kitchen. My family's business, Arthur Johnson's Menswear at 5th & "F" Streets in Eureka, suffered a lot more. They had large picture windows on the 5th Street side and many of them were broken. Oddly enough it wasn't the quake that broke them but the mannequins that were in the windows falling into the glass. What a mess! The inside of the store was more fortunate as piles of shirts, sweaters and pants landed on the floor but were not damaged. I will never forget it!
19	Phyllis Carlton	I was 14 when the earthquake happened and living on Warren Creek area between Arcata and Blue Lake. She was in the house whenthe earthquake happened standing in the hallway. She had to brace herself on the sides of the hall inorder not to fall and could see the room distorting as the seismic waves passed. Her sister was in a larger chair whic tilted over in the shaking. Her father was outside working in the two story chicken house and was terrified by the shaking. The major water main (more than a foot diameter) from Seasey dam ran by their property and was knocked off its supports by the shaking.
20	Rod Ledbetter	I was four and in the kitchen of my house on Parton Ln in Arcata. I remember being fascinated by a cup and suacer on the counter that slowly vibrated several feet along the counter top. The shaking stopped just as it reached the edge.
21	Judith StClaire	According to my uncle, the old Post Office building was packed with people. It was during Christmas rush, full of folks there to collect mail and people who left everything until the last minute to send mail. When the quake happened, the old building shook like crazy. The doorjamb changed shape enough to make the door unable to open. People inside panicked. My uncle had a very calm nature. I never saw him excited about anything. He was collecting mail from his mailbox when the quake happened. It was a heavy door and was wedged in pretty tight. It took him several minutes, but he was able to get the door open enough so that people could get out.
22	daughter of Holmes Eureka Lumber Co. employee	My father worked for Holmes Eureka Lumber Company and was working at his desk in Korbel when the earthquake occurred. He told me years later that during the earthquake his chair (with him sitting in it) slid across the floor and banged into the wall onthe other side of the office.
23	Margot Genger	I had just turned 3 and was in the bathtub with my mother on the third floor of our home. The water sloshed violently, and my mother grabbed me, but the shaking was so strong she couldn’t move. I don't remember much about the quake. I remember that the chimney was cracked; above the crack, it had rotated a bit but didn't fall.

24	Margot Genger's brother	My brother Robby would have been 4 at the time. He and my other brother, Tommy, 6 yrs old were returning my Dad's coke bottles to Cannom's grocery. Robby and Tommy were on K Street between 8th and 9th. The whole sidewalk started rolling. A man came out of the house on the corner of 8th and K and fell down. When the rolling stopped, what Robby remembers is that the sidewalk went back completely flat, no cracks.

Appendix S2: Contents of the assembled dataset at the Northern California Earthquake Data Center (https://ncedc.org/pub/assembled/Fickle_Hill_1954/)

(A) A copy of the paper describing this work, “Revisiting an Enigma on California's North Coast: The M6.5 Fickle Hill Earthquake of 21 December 1954”
(B) Set of seismogram scans from stations operated by Berkeley Seismographic Stations (BSS) and collaborators
(C) Accelerogram scans and digital records in SAC format for the United States Coast and Geodetic Survey triggered accelerometer stations at Eureka (EUR) and Ferndale (FER)
(D) Scans of the BSS recording sheet pages pertaining to the 21 December 1954 Fickle Hill earthquake
(E) Scans of the BSS 1954 Bulletin pages (Cover page, page providing hypocenter and origin time, pages providing arrival times)
(F) Scans of the ISC 1954 Bulletin pages (Cover page, page providing hypocenter and origin time, page providing arrivals)
(G) Scans of the USCGS 1954 Bulletin pages (Cover page, page providing hypocenter and origin time, page providing arrivals)
(H) Files used for relocation of the earthquake using NonLinLoc.
(I) The issue of the “Abstracts of earthquake reports for the Pacific Coast and the Western Mountain Region, 1 October 1954 to 31 December 1954” which includes reports for the Fickle Hill earthquake of 21 December 1954 (United States Coast and Geodetic Survey (1954a). Abstracts of earthquake reports for the Pacific Coast and the Western Mountain Region, 1 October 1954 to 31 December 1954, MSA-84, 50-96, Department of Commerce U.S. Coast and Geodetic Survey, MSA-84, San Francisco, CA)
(J) Intensity reports from Appendix S1 gathered as part of our research and outreach from sources including responses to an article in the Eureka Times Standard and to a query in the Humboldt County History Facebook Page; journal entries in the Susie Baker Fountain Papers from the Cal Poly Humboldt Library; and personal interviews.