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Analysis of microseismicity framing $M_w > 2.5$ earthquakes at The Geysers geothermal field, California

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The Geysers

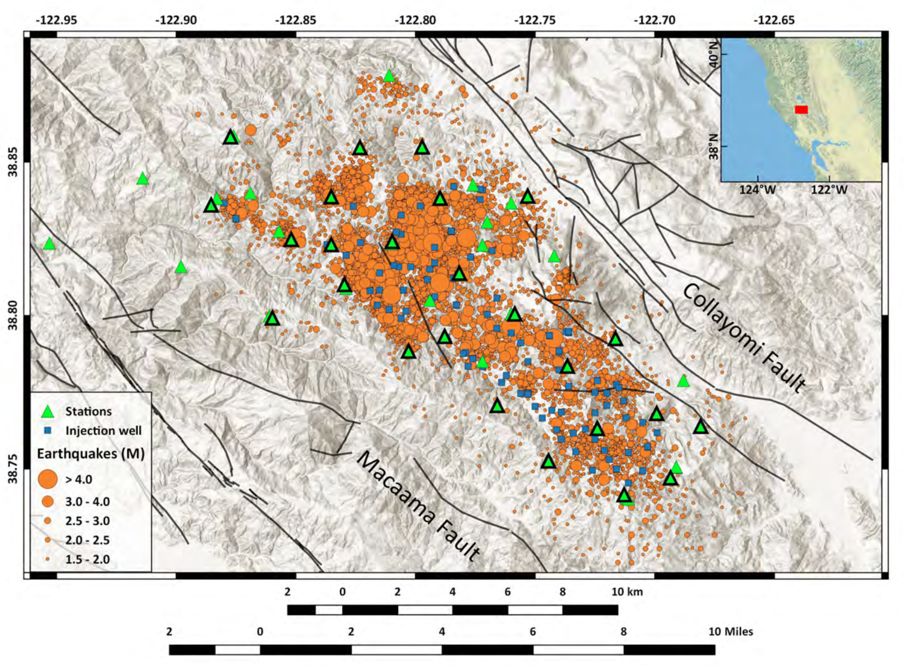

Figure 1: Overview map of The Geysers geothermal field with the main faults (black lines), injection wells (blue squares), occurring seismicity (M > 1.5) recorded during 2012 and 2013, and the deployed seismic stations (green triangles; black frames indicate the position of the temporary broadband instruments). Its position relative to the San Francisco Bay area is shown in the top right corner.

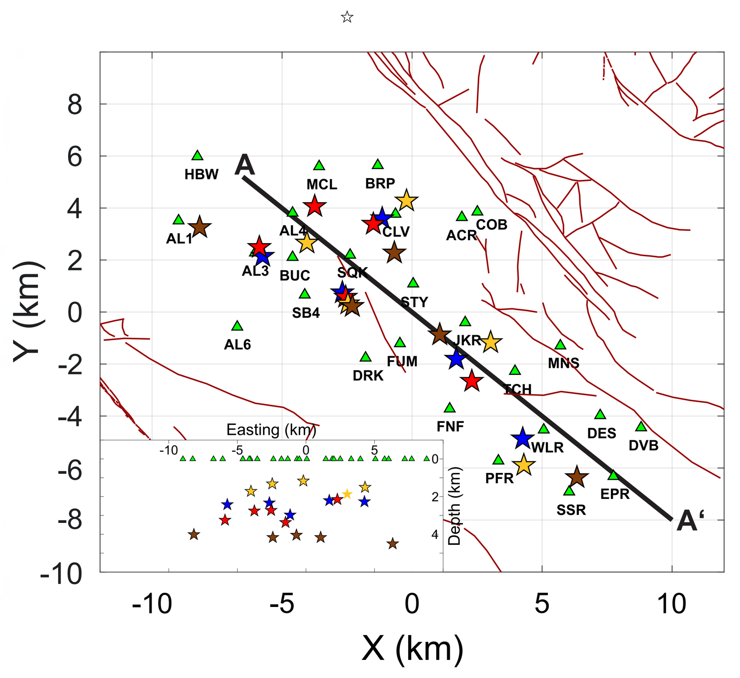

Figure 2: Location of the 20 master events with M > 2.5 analyzed in this study. Color codes are used to distinguish the different earthquake groups: red and blue indicate events located within the reservoir during low and high injection periods, respectively; yellow and brown indicate events located above and below the reservoir, respectively.

Short summary

- Magnitude frequency distribution varies significantly across earthquake sequences between the Northwestern and Southeastern part of The Geysers.
- The reservoir responds differently to the occurrence of a large event, stress-triggered aftershocks are mostly restricted to the Northwestern part.
- Due to extensive damage, large events grow spontaneously from smaller pre-ruptures in the southeast of the geothermal field.

Methodology

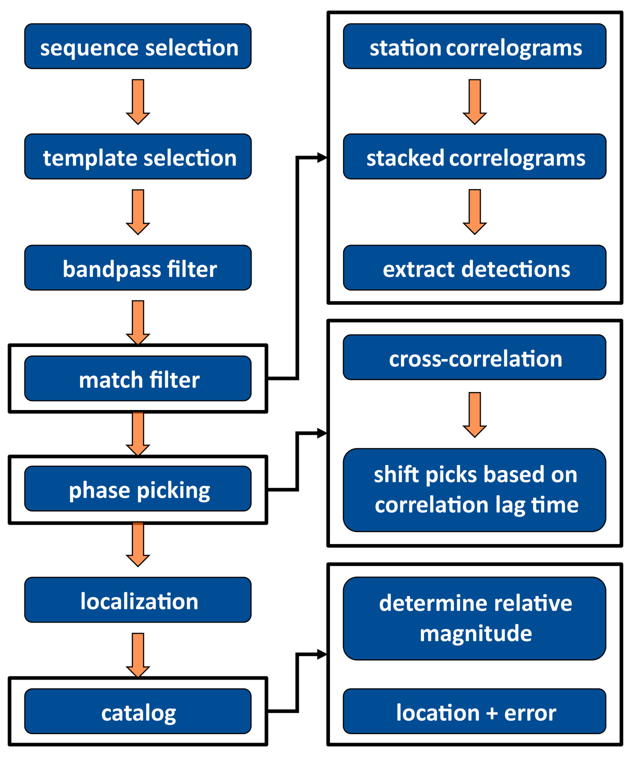

Figure 3: Flow chart of the analysis steps performed in this study. On the left are all individual steps in chronological order, on the right is detailed information on the core steps.

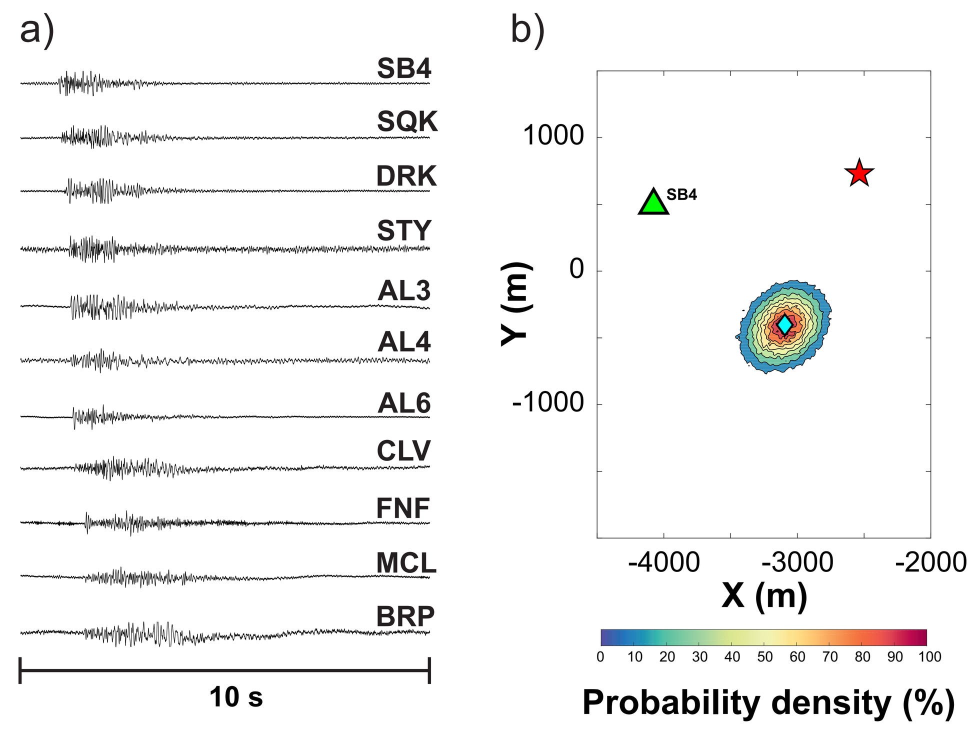

Figure 4: Example detection on the 13/01/2013 at 17:24:44 GMT with 0.7 M_L. a) 10 s of waveforms across the network. b) The result of the Metropolis-Hastings localization algorithm, the initial location is indicated by the red star, the best fit solution including its probability density function is shown surrounding the blue diamond.

Changes of b-value

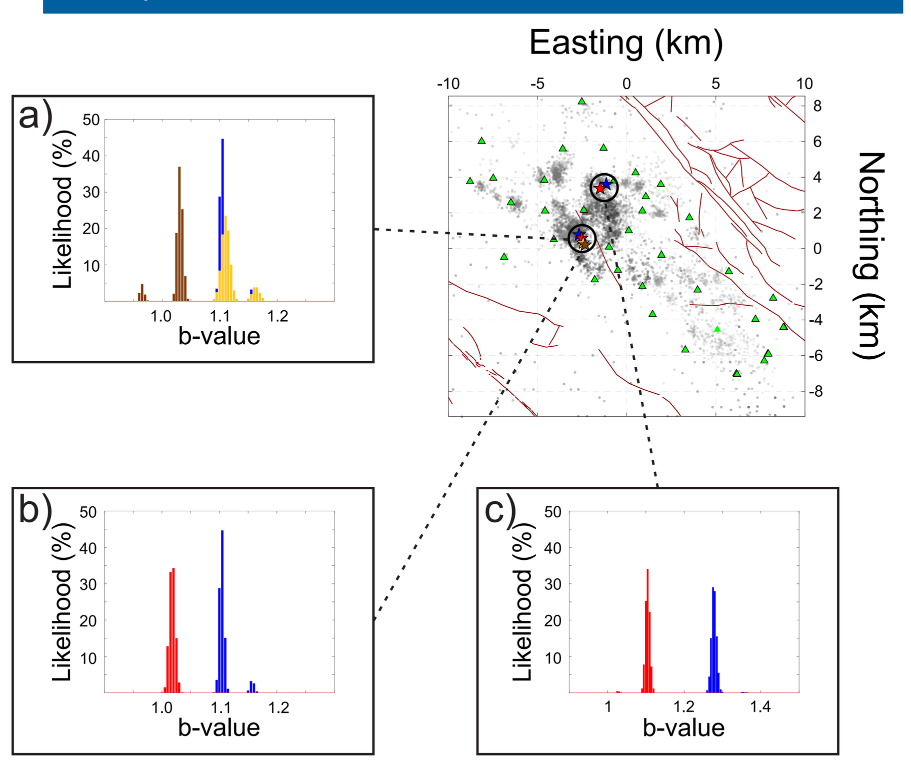

Figure 6: Comparison of b-values determined: a) between three collocated sequences with different depths, b) and c) between collocated sequences during high and low injection period. Yellow represents sequences above the reservoir, brown below the reservoir. Blue and red indicate sequences during high and low injection periods, respectively.

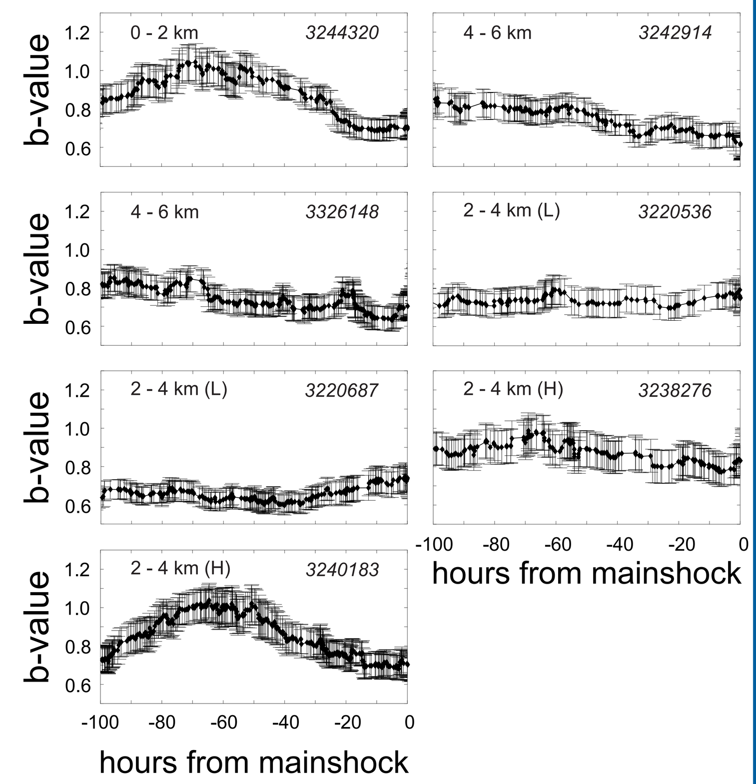

Figure 7: Temporal evolution of the b-value leading up to the mainshock for sequences containing a sufficiently large number of earthquakes. The moving b-value was calculated using overlapping equal number, 100, event windows. (H) and (L) in the caption indicates high and low injection periods, respectively.

Sequence properties

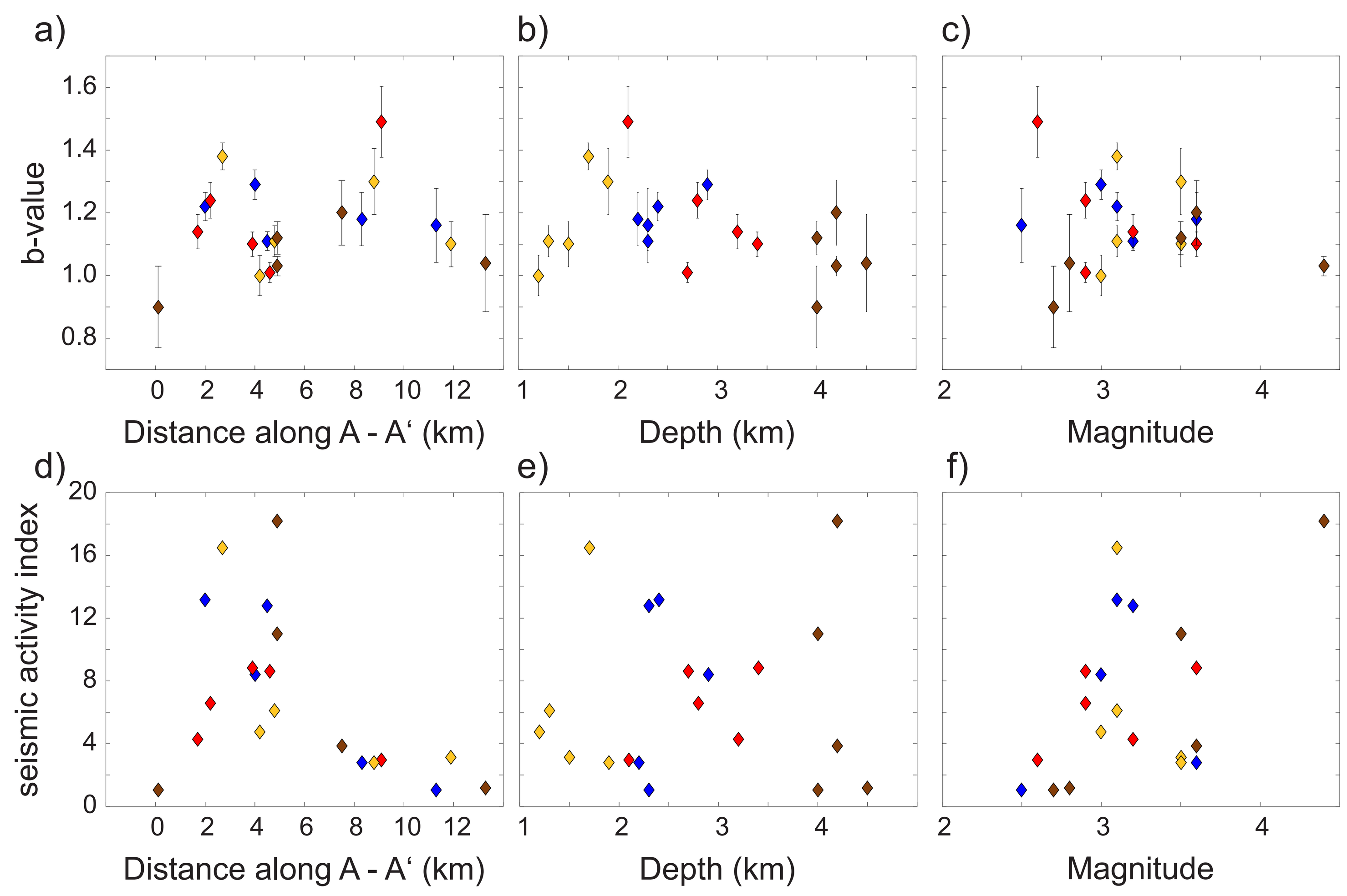

Figure 5: Comparison between the b-value and a) position across the geothermal field (see Figure 2), b) depth, and c) magnitude. Comparison between the seismic activity index, i.e. the number of detections normalized by the number of templates and d) position across the geothermal field (see Figure 2), e) depth, and f) magnitude. Yellow diamonds indicate shallow events between 0 – 2 km depth, blue and red show events at 2 – 4 km depth during high and low injection periods, respectively, and brown represents events below the reservoir.

Reservoir response

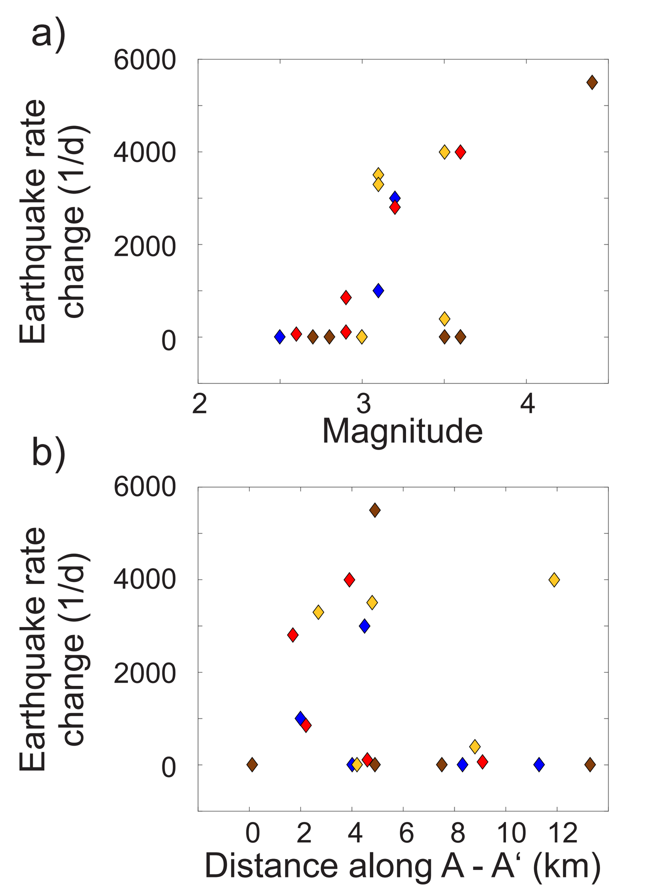

Figure 8: Earthquake rate changes around the time of the mainshock for each sequence. Comparison against a) depth, and b) position across the geothermal field (see figure 2). Yellow diamonds indicate shallow events between 0 – 2 km depth, blue and red show events at 2 – 4 km depth during high and low injection periods, respectively, and brown represents events below the reservoir.

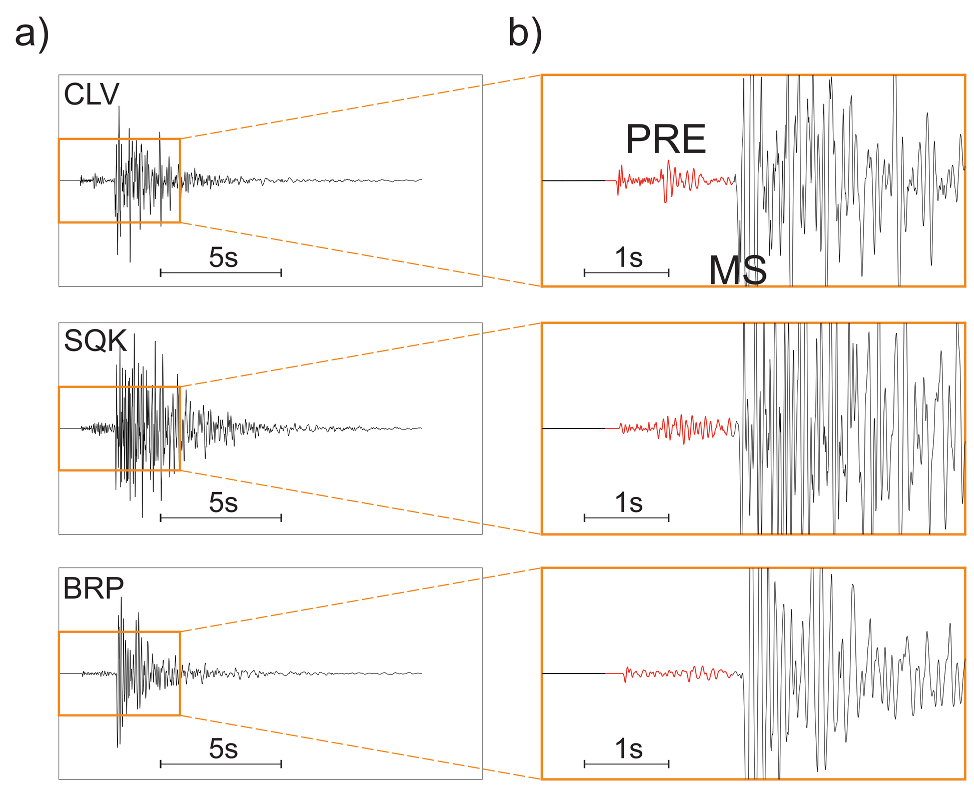

Figure 9: Example of a pre-rupture or double event (Event ID: 3238276). a) Full recording of the waveform on the three closest station, as indicated in the bottom left of each subfigure. b) Zoom into the first few seconds of the earthquake seismogram, a pre-rupture (PRE), marked in red, is clearly visible before the onset of the mainshock (MS).

Acknowledgments

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This research is in preparation to be submitted in *JGR: Solid Earth*