AGU PUBLICATIONS

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Supporting Information for

Moment Tensors of Ring-Faulting at Active Volcanoes: Insights into Vertical-CLVD Earthquakes at the Sierra Negra Caldera, Galápagos Islands

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Captions for Datasets S1 to S4

Introduction

In Text S1, we conduct three-element MT inversion for estimating the resolvable moment tensor ($\boldsymbol{M}_{res}$) of the vertical-T CLVD earthquake at the Sierra Negra caldera in 2005. In Data Sets S1–S4, we provide solutions of MT inversions for the earthquake obtained in Section 3 and Text S1. Data Sets are available in an open access repository, Zenodo (https://zenodo.org/record/4414990).

Text S1. Inversion with the constraint of zero *DS* component

In Main Text, we obtain $\boldsymbol{M}_{res}$, defined by Equation (11), for the vertical-T CLVD earthquake at the Sierra Negra caldera in 2005 as follows: (1) estimate five independent MT elements by the inversion assuming the zero trace ($M_{rr} + M_{\theta\theta} + M_{\phi\phi} = 0$), and then (2) remove the indeterminate *DS* component ($\boldsymbol{M}_{DS}$) by setting $M_{r\theta} = M_{r\phi} = 0$. On the other hand, $\boldsymbol{M}_{res}$ can be obtained directly by the inversion for only three independent MT elements with the constraints of zero *DS* component, or $M_{r\theta} = M_{r\phi} = 0$, as well as the zero trace (e.g., Kanamori and Given, 1981). Here, we estimate $\boldsymbol{M}_{res}$ of the vertical-T CLVD earthquake by the three-element MT inversion. For the inversion, we basically follow the five-element MT inversion method in the 3D space, as explained in Section 3.2, but with the additional constraint of $M_{r\theta} = M_{r\phi} = 0$. We use the same dataset composed of the 25 seismic records.

Figure S1a shows the global NRMS values for $\boldsymbol{M}_{res}$ solutions at locations on the x–y plane at a depth of 2.5 km below the solid surface that are obtained by the three-element MT inversion. In a small area around the Sierra Negra caldera (white rectangle in Figure S1a), the NRMS values are small. Figure S1b shows the global NRMS values for $\boldsymbol{M}_{res}$ solutions on the x–z plane along latitude 0.83°S (dashed line in Figure S1b). Similarly, small NRMS values are yielded by most of the solutions in the shallow crust. The solution at the caldera (0.83°S, 91.14°W; red circle in Figure S1a) at a depth of 2.5 km reproduces the observations well with an NRMS value of 0.394 (Figure S2). From the $\boldsymbol{M}_{res}$ solutions in the 3D space, 36 solutions at different centroid grids yield NRMS values of ≤ 0.394.

In Figures S1c and S1d, we show $\boldsymbol{M}_{res}$ estimated by the three-element MT inversion at centroid locations on the x–y and x–z planes, respectively. $\boldsymbol{M}_{res}$ on the two planes have very similar focal mechanisms and M_w. For the 36 solutions with small NRMS values of ≤0.394, M_w values are in a narrow range (5.33 ± 0.03) (Figure S3a); the solutions also contain stable values of the CLVD ratio k_{CLVD} (73.0% ± 2.2%; Figure S3b) and the N-axis azimuth ψ (102.8° ± 1.5°; Figure S3c). These values are almost the same as those of $\boldsymbol{M}_{res}$ obtained by the five-element MT inversion method in Main Text (See Section 3.3 and Figure 8c–e). Thus, the two different methods for estimating $\boldsymbol{M}_{res}$ yield almost equivalent results when using the good datasets.

We note that the $\boldsymbol{M}_{res}$ solutions obtained by the three-element MT inversion do not contain the *DS* component ($M_{r\theta} = M_{r\phi} = 0$); however, the global NRMS values of ≤0.394 for the $\boldsymbol{M}_{res}$ solutions are almost comparable to the values of ≤ 0.365 for the solutions including the *DS* component estimated by the five-element MT inversion in Main Text (See Section 3.3 and Figure 6). This demonstrates that most of the long-period seismic waves of the earthquake are originated from the *CLVD* and *SS* components, whereas the *DS* component has little contribution to excitations of long-period seismic waves, as discussed in Section 4.1.

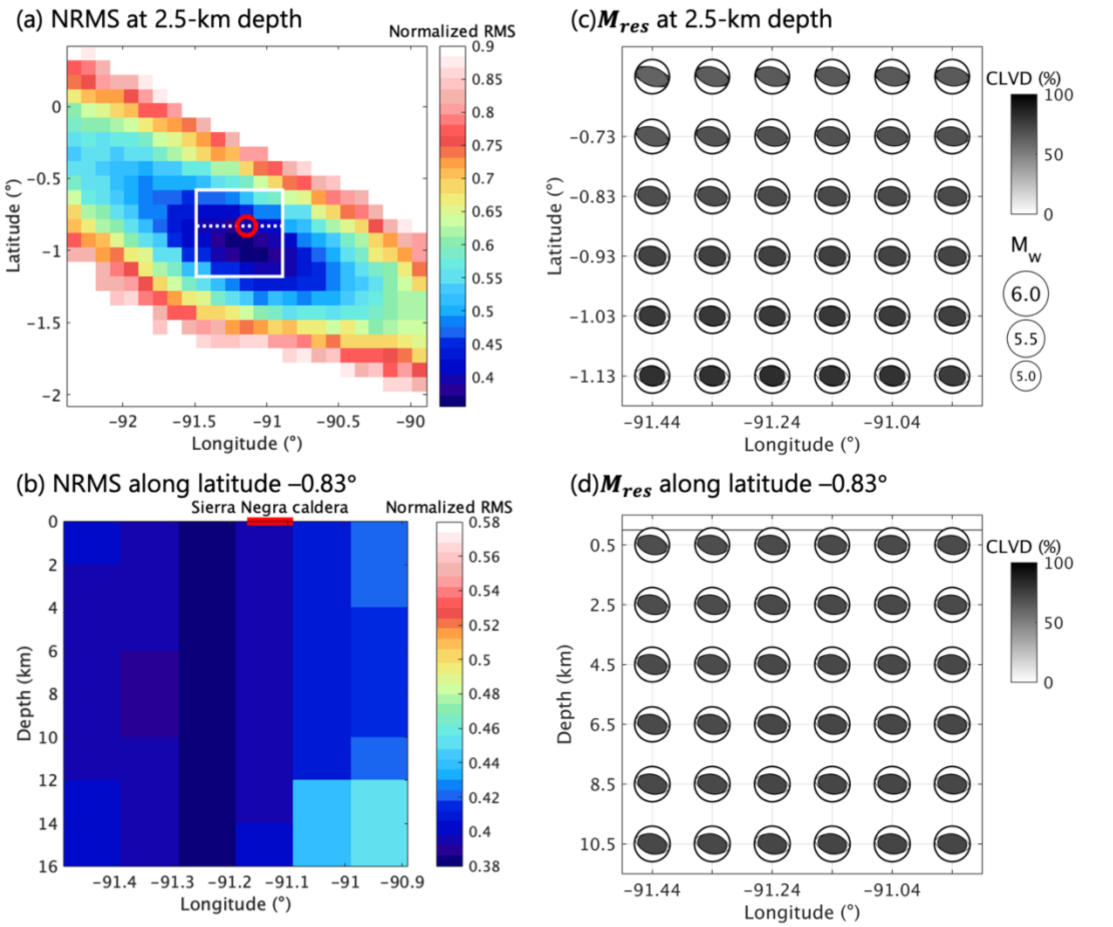

Figure S1. Three-element MT inversion with the constraint of zero *DS* component for the vertical-T CLVD earthquake of 22 October 2005 at the Sierra Negra caldera. (a–b) NRMS misfits of $\boldsymbol{M}_{res}$ solutions inverted by the three-element MT inversion at source locations distributed on (a) the x–y plane at a depth of 2.5 km in the crust and (b) the x–z plane along a latitude of 0.83° (dashed white line in (a)). The red circle in (a) and the red line in (b) represent the approximate locations of the Sierra Negra caldera. (c–d) $\boldsymbol{M}_{res}$ solutions at different centroid locations on (c) the x–y plane around the caldera (in the area shown by the white rectangle in (a)) and (d) the x–z plane. All focal mechanisms are shown by projection of the lower focal hemisphere. In (b) and (d), the vertical axis represents the centroid depth in the crust.

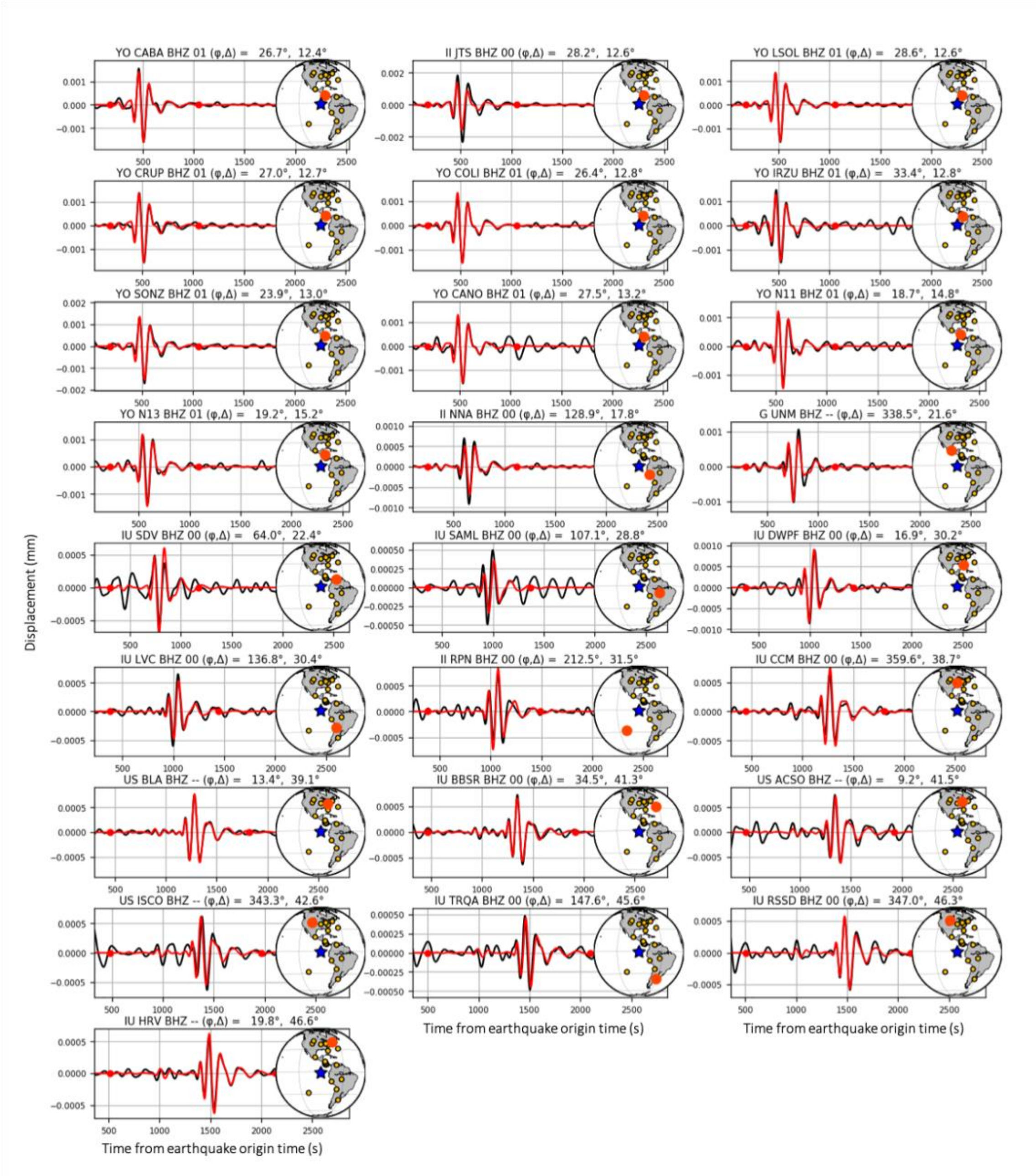

Figure S2. Model performance of three-element MT inversion with the constraint zero *DS* component for the M_w 5.5 vertical-T CLVD earthquake of 22 October 2005. Red and black lines represent synthetic and observed waveforms, respectively. The start and end points of the inversion time window are indicated by red circles. In each inset map, the blue star and large red circle represent locations of the epicenter (0.83°S, 91.14°W) and the station. The station azimuth (*φ*) and epicentral distance (*Δ*) are indicated at the top of each panel. Note that the observations are well-reproduced even without the *DS* component.

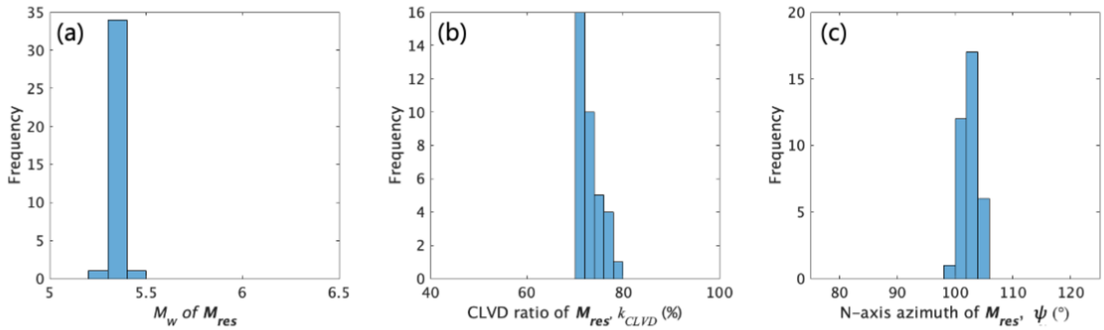

Figure S3. Histogram of the parameters of *Mres* solutions with small NRMS values.**

(a) M_W, (b) the CLVD ratio k_{CLVD}, and (c) the N-axis azimuth ψ of $\boldsymbol{M}_{res}$ solutions yielding small NRMS values of ≤ 0.394, which are estimated by the three-element MT inversion with the constraint of zero *DS* component.

Reference

Kanamori, H., & Given, J. W. (1981). Use of long-period surface waves for rapid determination of earthquake-source parameters. *Physics of the Earth and Planetary Interiors*, *27*(1), 8–31. https://doi.org/10.1016/0031-9201(81)90083-2

Data Set S1. MT solutions obtained by the five-element MT inversion on the x-y plane with the constraint of zero trace, which is conducted in Section 3. The solutions are used for Figures 7a, 7c and 7e.

Data Set S2. Same as Data Set S1, but on the x-z plane. The solutions are used for Figures 7b, 7d and 7f.

Data Set S3. $\boldsymbol{M}_{res}$ solutions obtained by the three-element MT inversion on the x-y plane with the constraints of zero trace and zero *DS* component, which is conducted in Text S1. The solutions are used for Figures S1a, and S1c.

Data Set S4. Same as Data Set S3, but on the x-z plane. The solutions are used for Figures S1b, and S1d.