

# Supporting Information for “Near-orthogonal orientations of active conjugate faults in the Anza-Borrego shear zone, Southern California”

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### Text S1. Description of LINSKAN algorithm

LINSKAN is based on OPTICS (Ordering Points to Identify the Clustering Structure), a density-based clustering algorithm. OPTICS uses three parameters for clustering,  $\epsilon$ ,  $MinPts$ , and  $\xi$ .  $\epsilon$  is the maximum distance to consider when confining a cluster,  $MinPts$  describes the minimum number of points required to define a cluster, and  $\xi$  determines the minimum steepness to determine the local minimum of *reachability distance*, which constitutes the boundary of a cluster. OPTICS first searches for *core points* in the data, which is defined as a point with at least  $MinPts$  of points found within its neighborhood of  $\epsilon$  distance. For each of the *core point*, it defines a *core distance*, which is the distance between a *core point* and its  $MinPts$ -th closest point. Next, OPTICS calculates the *reachability distance* among all core points. The *reachability distance* between points a and b is either the distance between a and b or the *core distance* of a, whichever is larger. Points that don't have at least  $MinPts$  of points found within its neighborhood of  $\epsilon$  distance won't be classified as a *core point*, so their *core distance* and *reachability distance* are undefined. Points within a cluster have a low *reachability distance* to their most adjacent neighbors, so points with local minimum *reachability distance* are identified as one cluster.

Since OPTICS uses the Euclidean metric to define clusters, the shape of clusters only depends on their density structure and is not necessarily linear. LINSKAN keeps the basic method of OPTICS but replaces the Euclidean metric with a distance function derived from Kullback-Leibler Divergence, which is the measurement of similarity between two distributions. In this way, the clustering results will be more linear. In LINSKAN we

not only keep  $\epsilon$ ,  $MinPts$ , and  $\xi$ , but also introduce two additional parameters:  $ecc\_pts$  and  $threshold$ . For each point, LINSKAN approximates its  $ecc\_pts$  nearest neighbors as a normal distribution. Then, for clustering, we define the pairwise distance between  $P = \mathcal{N}(\mu_P, \Sigma_P)$  and  $Q = \mathcal{N}(\mu_Q, \Sigma_Q)$  to be:

$$\begin{aligned} D(P, Q) = & \frac{1}{2} \|\Sigma_Q^{-\frac{1}{2}} \Sigma_P \Sigma_Q^{-\frac{1}{2}} - I\|_F \\ & + \frac{1}{2} \|\Sigma_P^{-\frac{1}{2}} \Sigma_Q \Sigma_P^{-\frac{1}{2}} - I\|_F \\ & + \frac{1}{\sqrt{2}} \|\mu_P - \mu_Q\|_{\Sigma_Q^{-1}} \\ & + \frac{1}{\sqrt{2}} \|\mu_P - \mu_Q\|_{\Sigma_P^{-1}} \end{aligned} \quad (1)$$

where  $\|A\|_F$  denotes the frobenius norm of the matrix  $A$  and

$$\|x\|_A = \sqrt{x^T A x} \quad (2)$$

denotes the elliptic norm defined by  $A$  for vector  $x$  and matrix  $A$ . This distance can be viewed as a low-order approximation of the symmetrized KL-divergence.

The  $threshold$  parameter represents the minimum correlation coefficient. All clusters with correlation coefficients lower than the  $threshold$  won't be included in the final result.

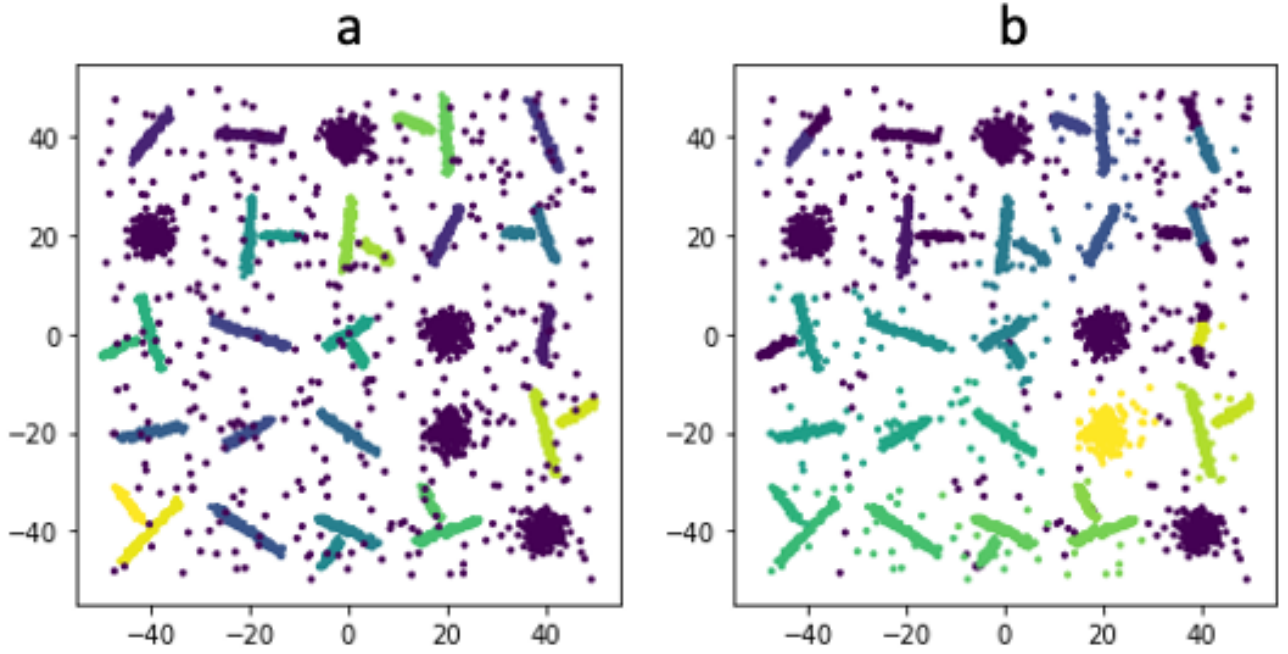
With all parameters being set, LINSKAN will go through each point in the dataset and label it either as a member of linear clusters with a sufficient correlation coefficient or an unqualified data point.

With synthetic data, LINSKAN is proven accurate in linear clustering. After testing LINSKAN on randomly generated synthetic data with noise, non-linear clusters, and linear clusters, we found that LINSKAN can correctly identify as much as 82.36% of true linear cluster data points and in this scenario, the ratio between false positive points and true linear cluster points is 0.1636 (Figure S1).

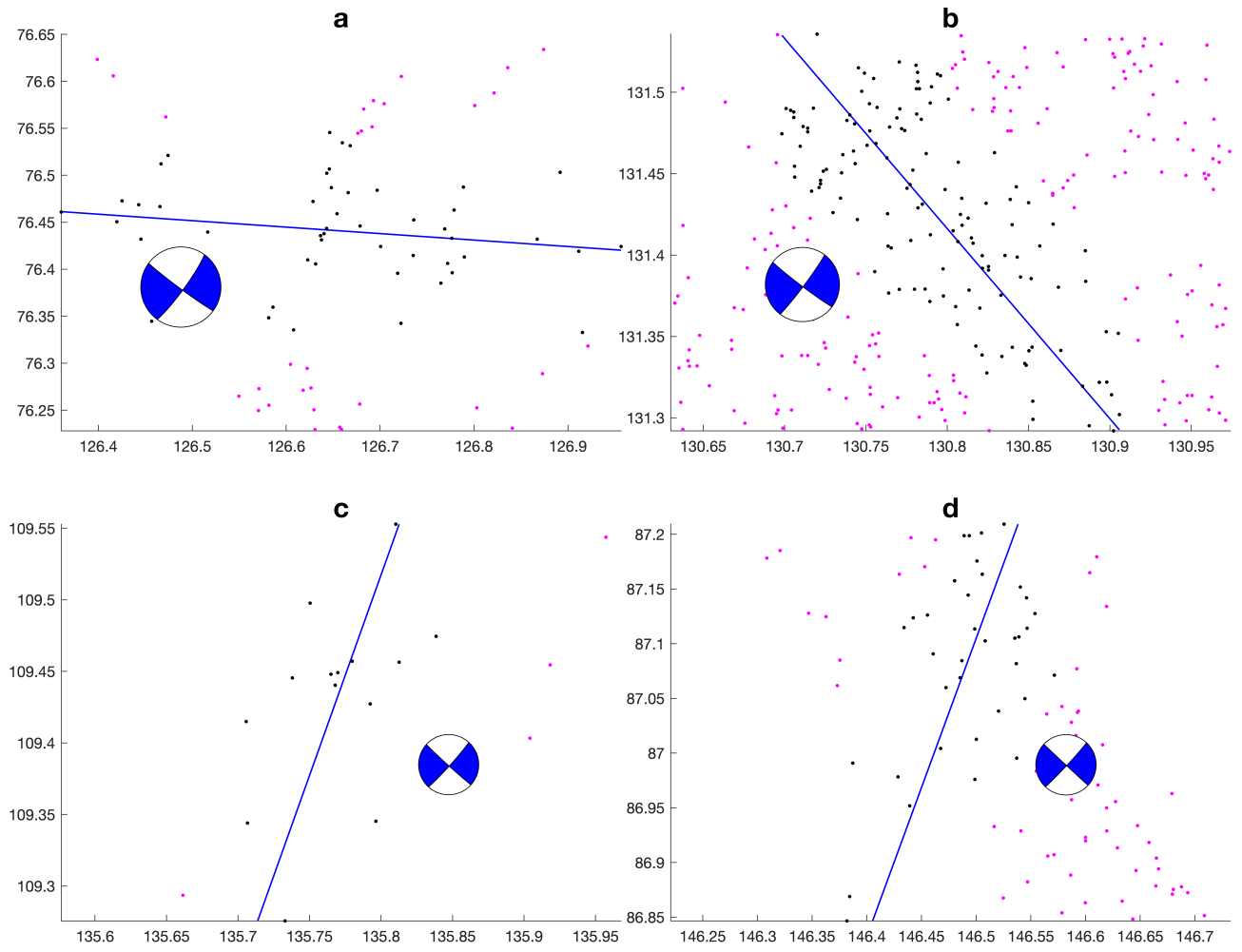
**References**

- Fialko, Y., & Jin, Z. (2021). Simple shear origin of the cross-faults ruptured in the 2019 Ridgecrest earthquake sequence. *Nature Geoscience*, *14*, 513–518.

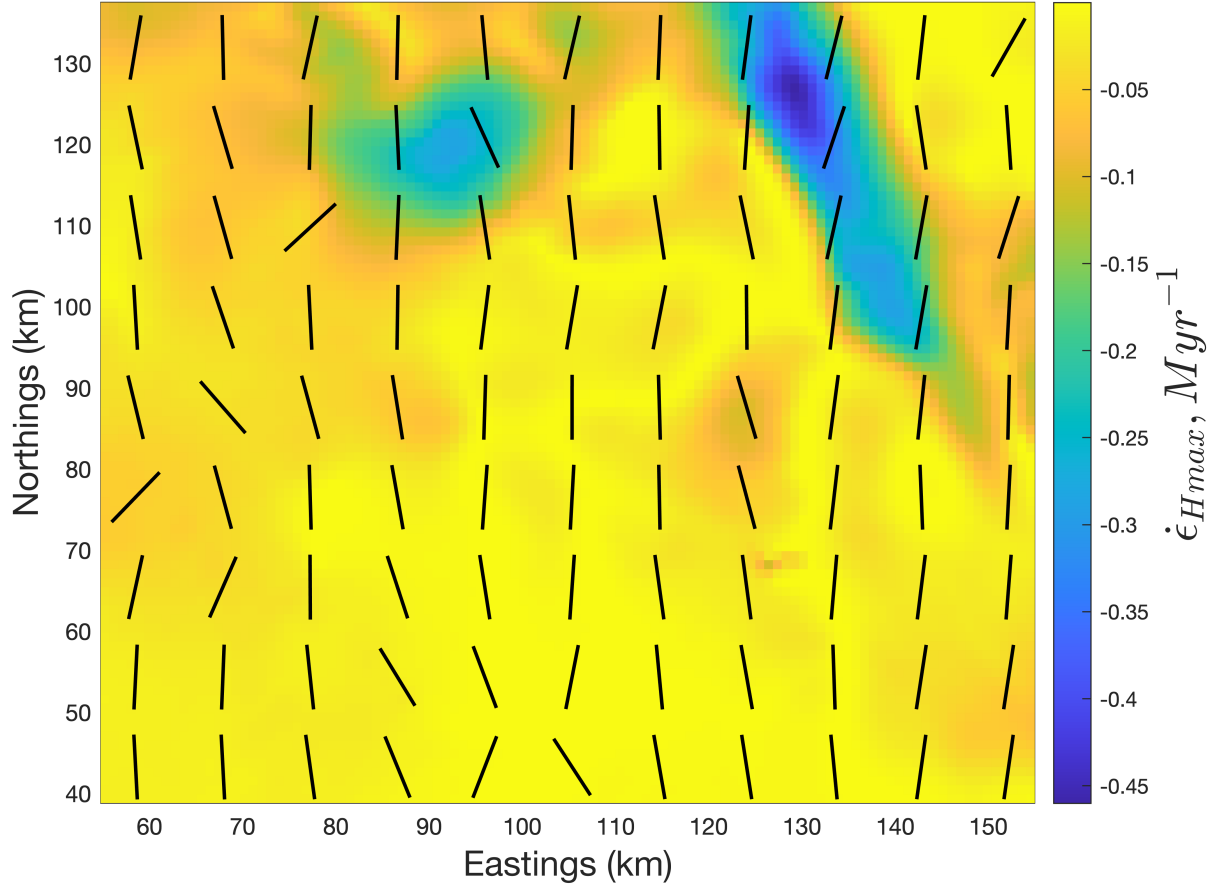




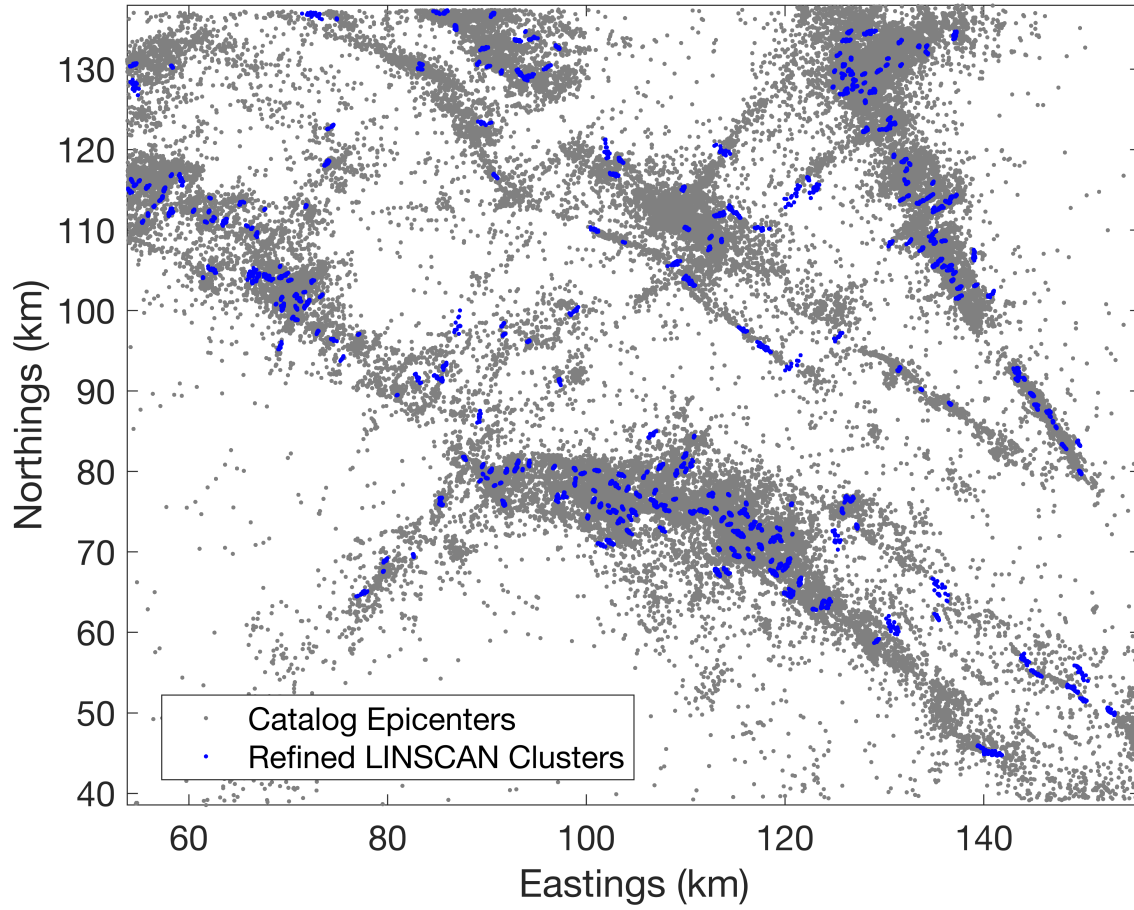
**Figure S1.** (a) A synthetic data set mimicking a distribution of earthquake epicenters. Purple points represent "noise" (i.e., background seismicity, and irregular or quasi-isometric clusters). Linear clusters are denoted by sets of points having the same color (other than purple). (b) LINSCAN classification: color (non-purple) sets of points denote identified linear clusters, and purple points represent the remaining data (i.e., data points that were not identified as belonging to a linear cluster).



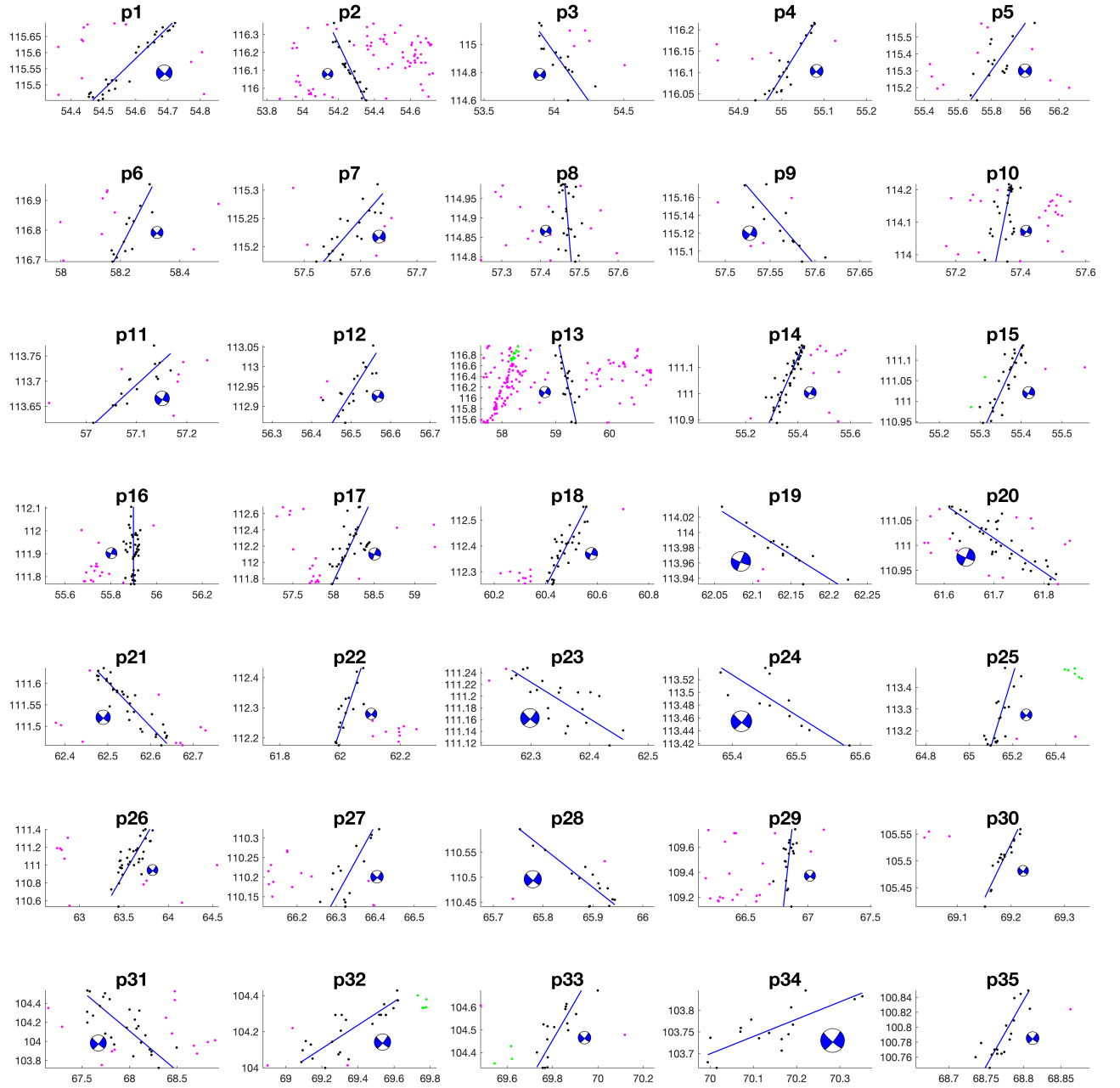
**Figure S2.** Examples of clusters selected by LINSKAN that failed to pass a visual quality check. Panels (a) and (d) illustrate clusters which contain smaller linear features that are not aligned with the overall trend. Panel (b) illustrates a selected cluster which is not obviously distinguishable from the background. Panel (c) illustrates a quasi-linear cluster with points that are unevenly and/or sparsely distributed.



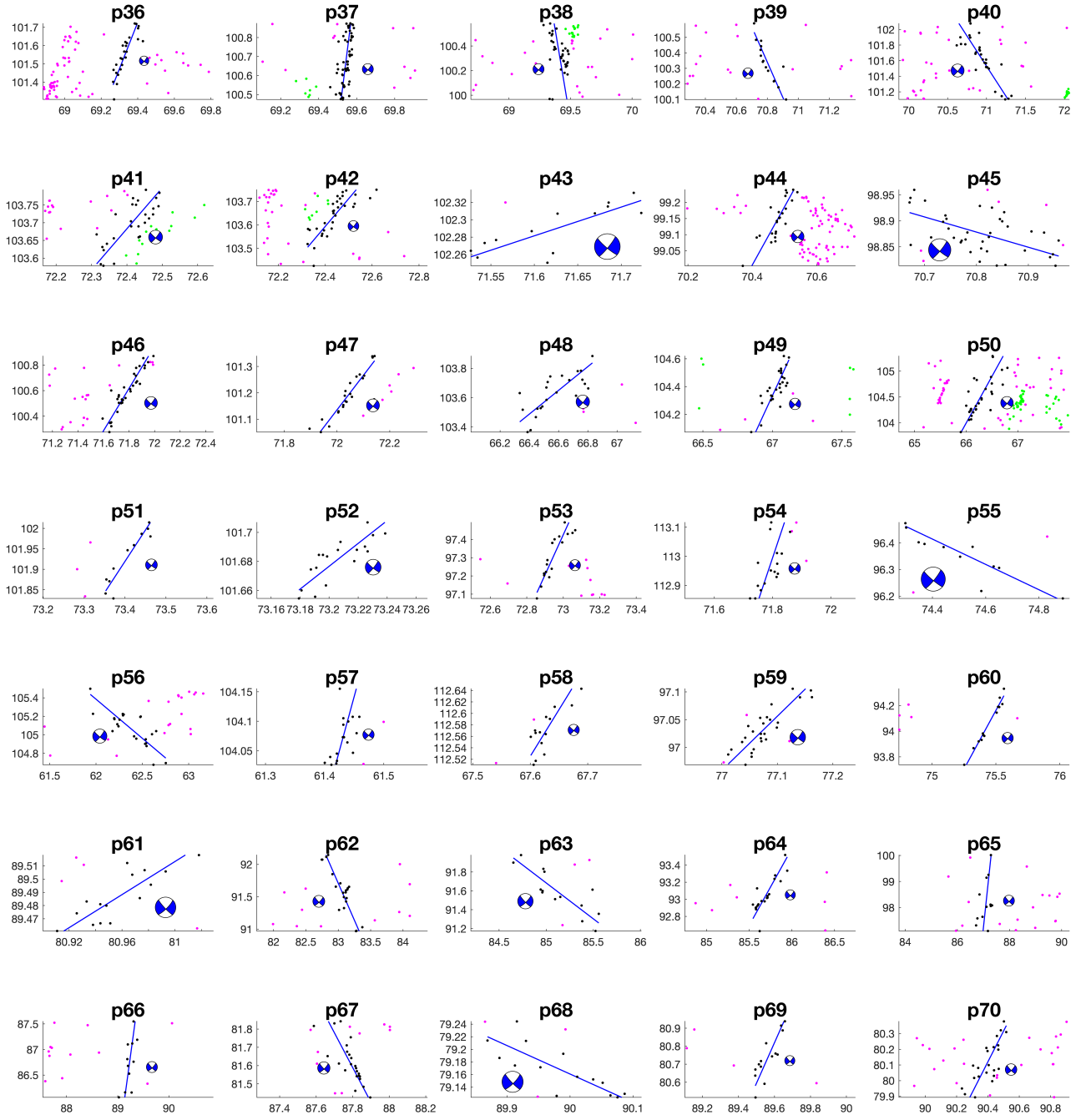
**Figure S3.** The magnitude (color) and orientation (black tick marks) of the maximum compressive strain rate in the study area calculated from the GNSS-derived secular velocities (for details, see Methods in Fialko & Jin, 2021).



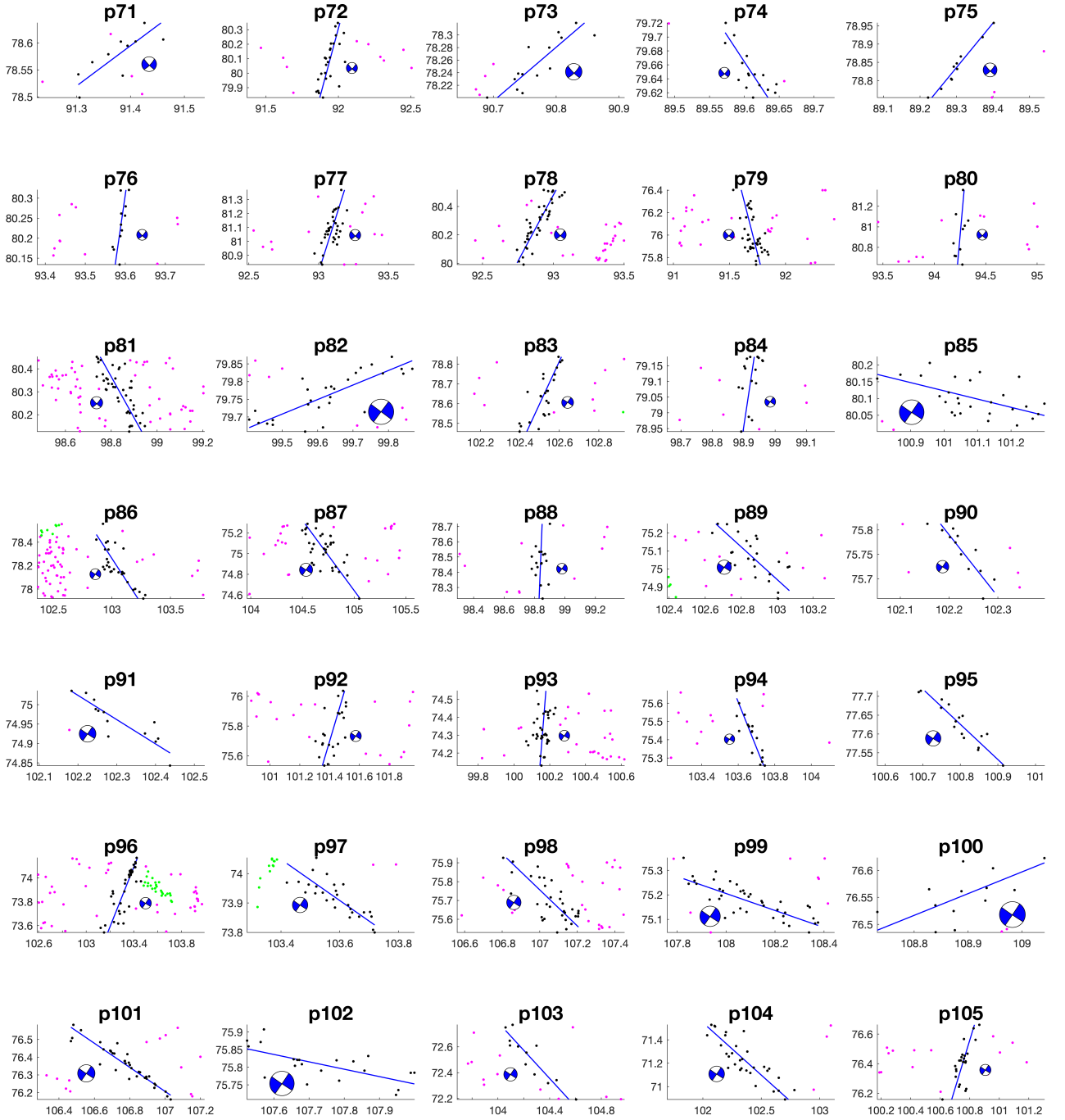
**Figure S4.** A set of quasi-linear clusters that passed the quality checks (blue dots). A total of 375 clusters are selected. Other notation is the same as in Figure 2 in the main text.



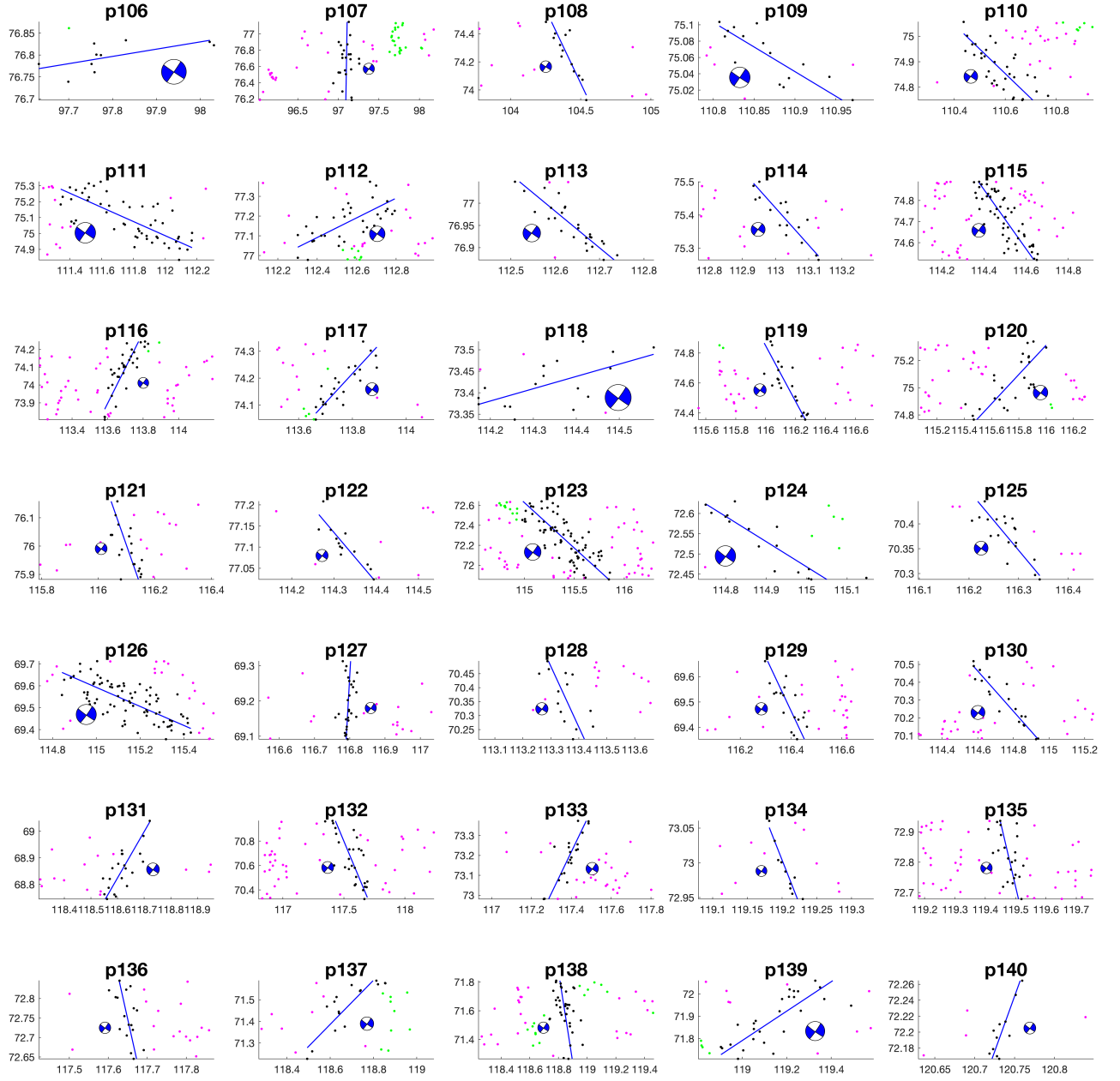
**Figure S5.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



**Figure S6.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.

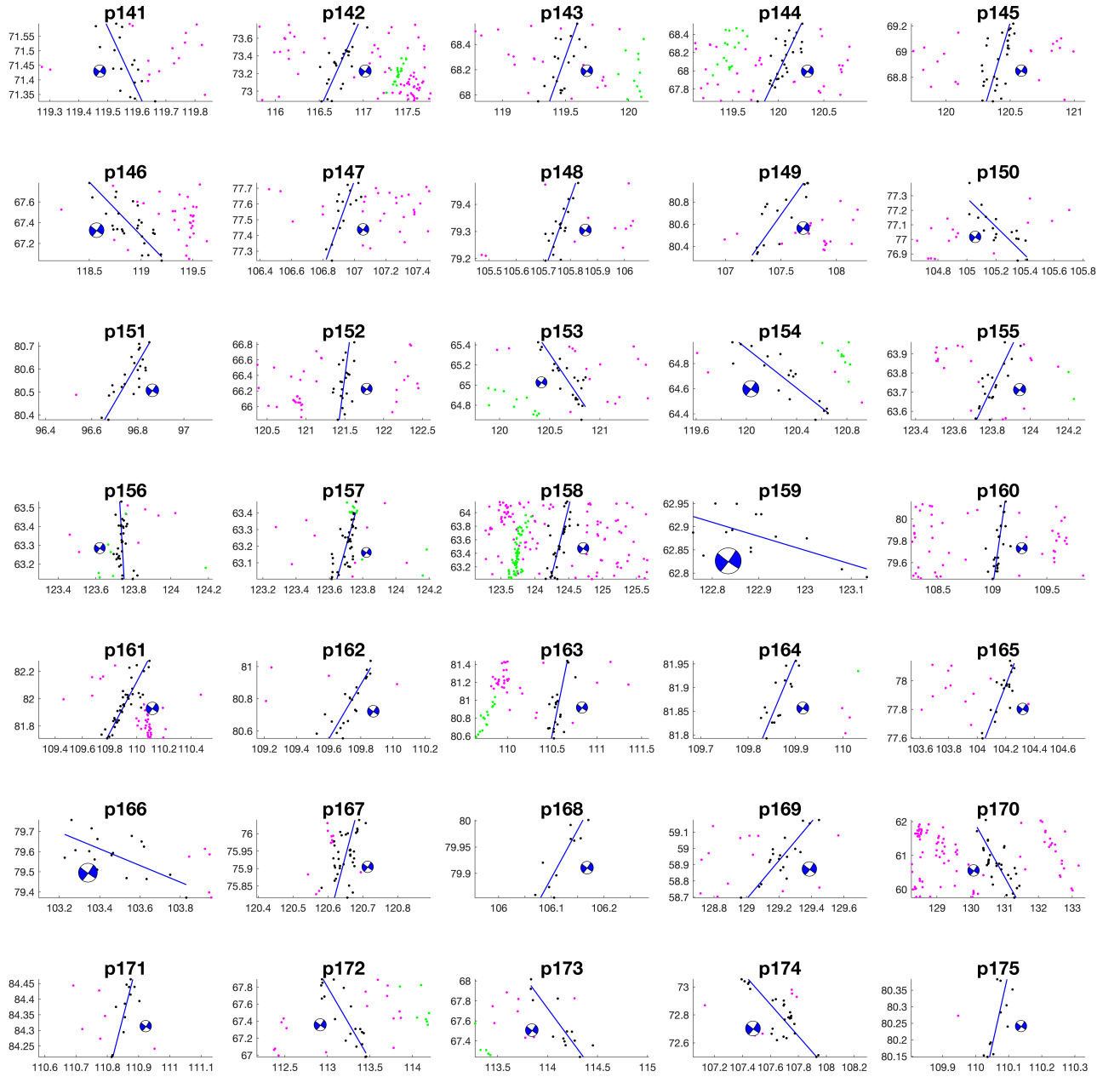


**Figure S7.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.

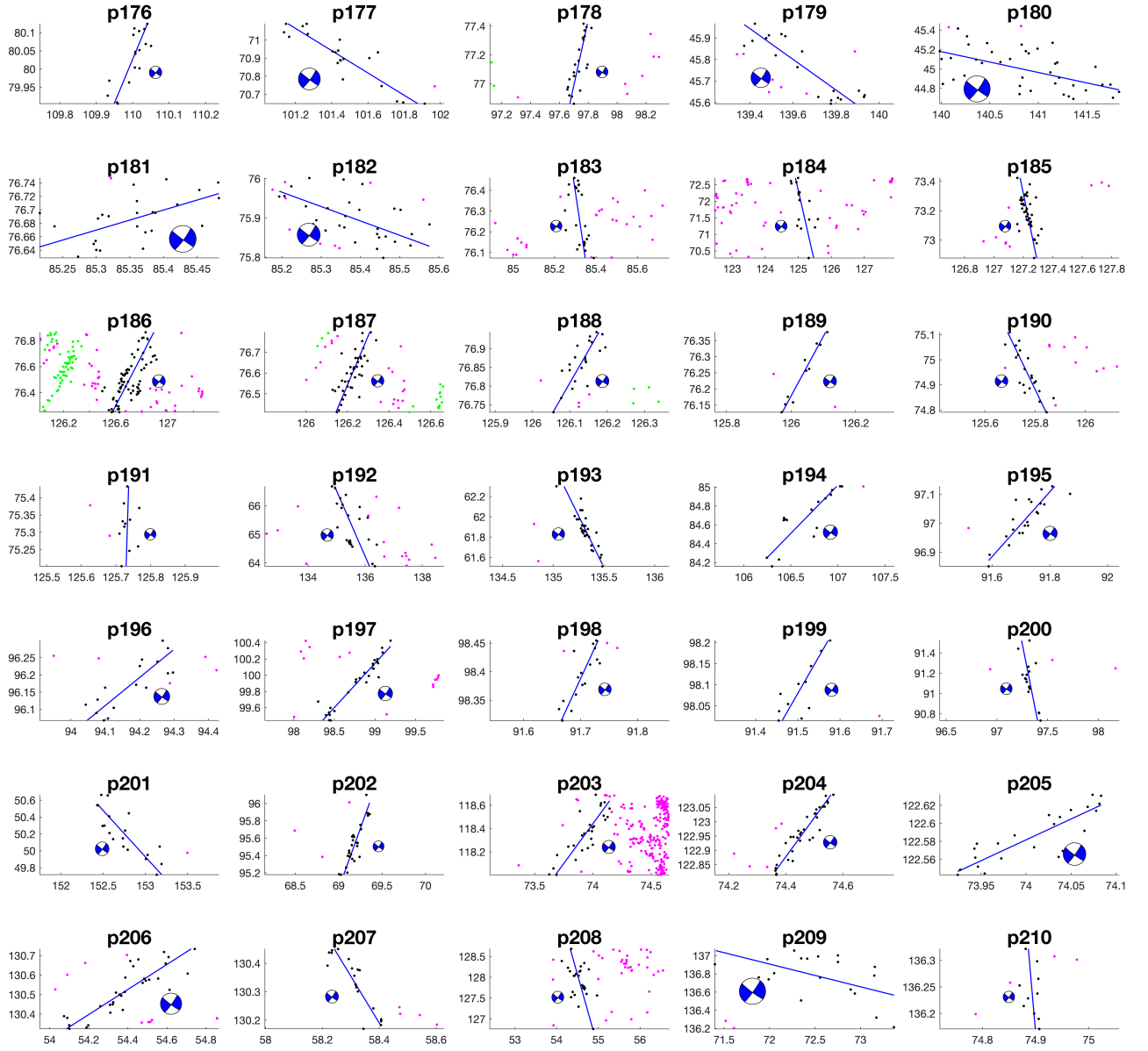


**Figure S8.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.

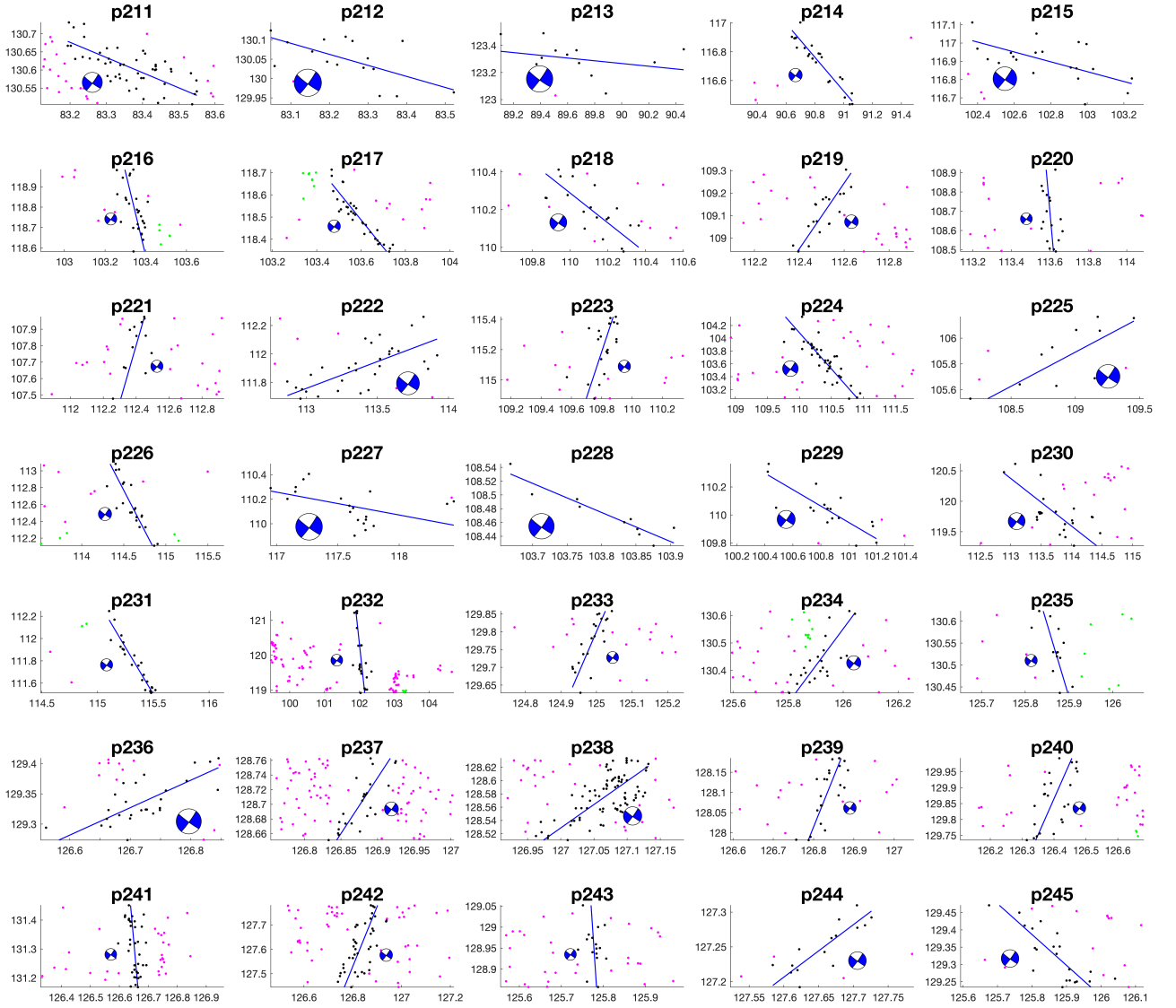




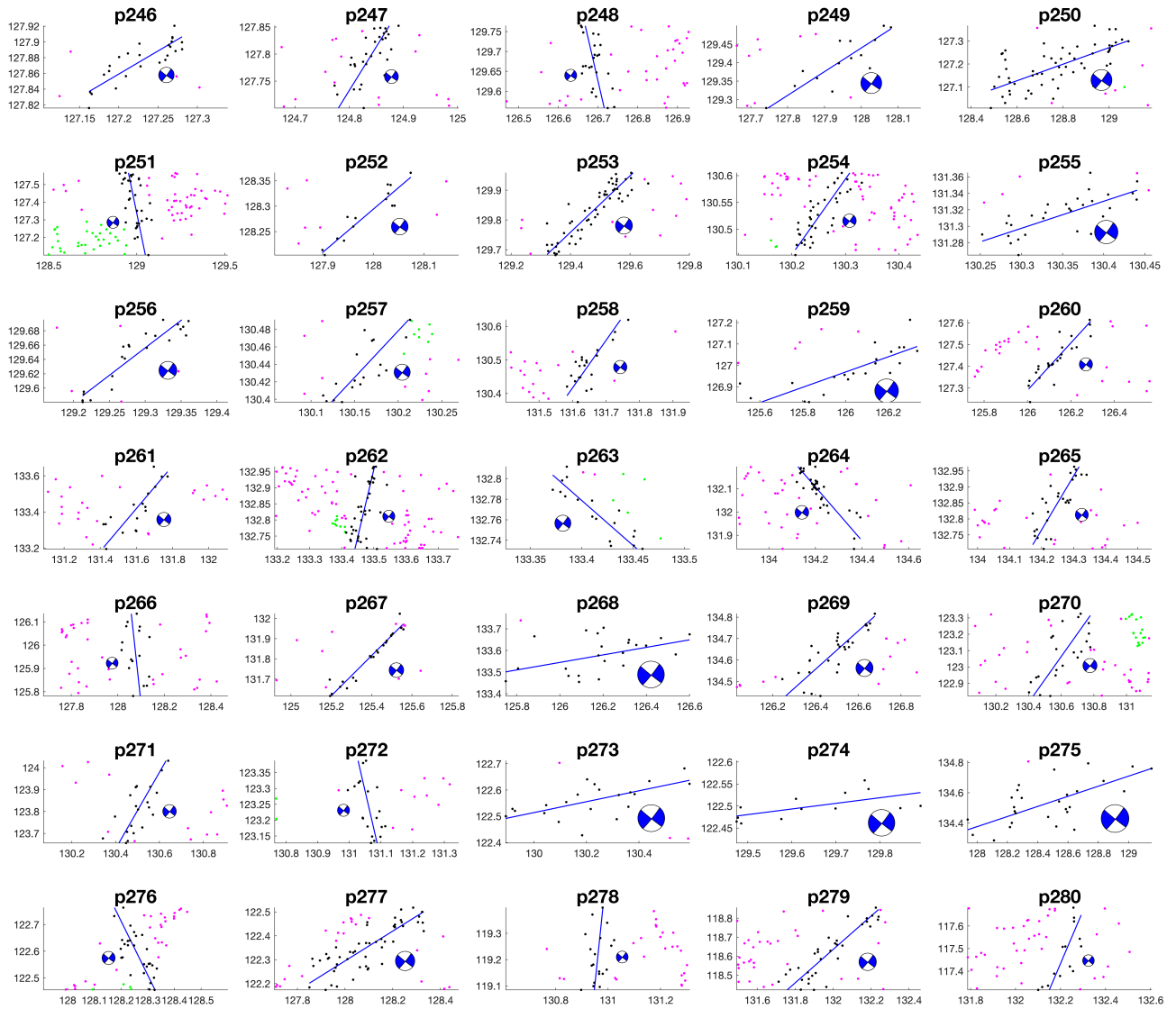
**Figure S9.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



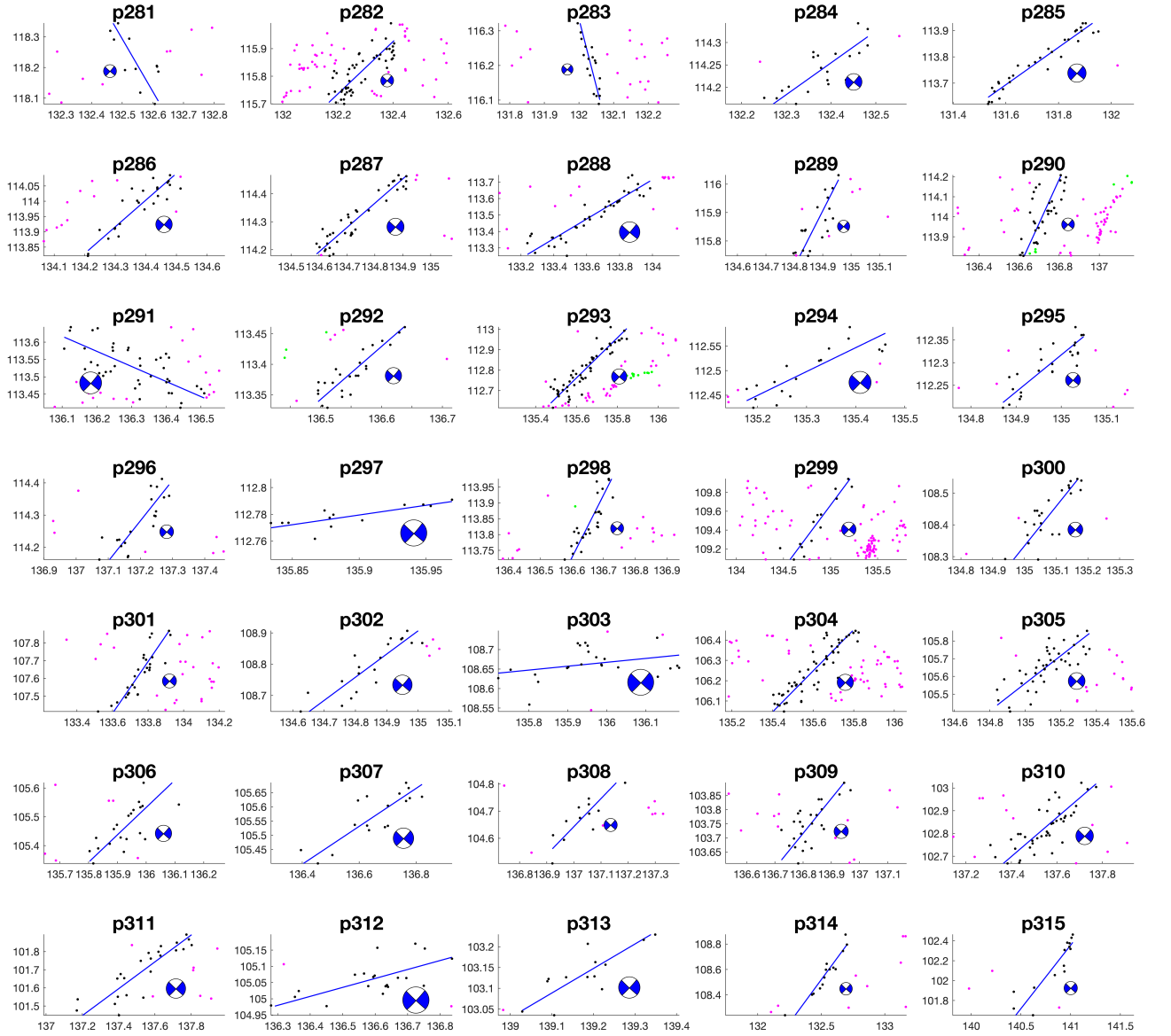
**Figure S10.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



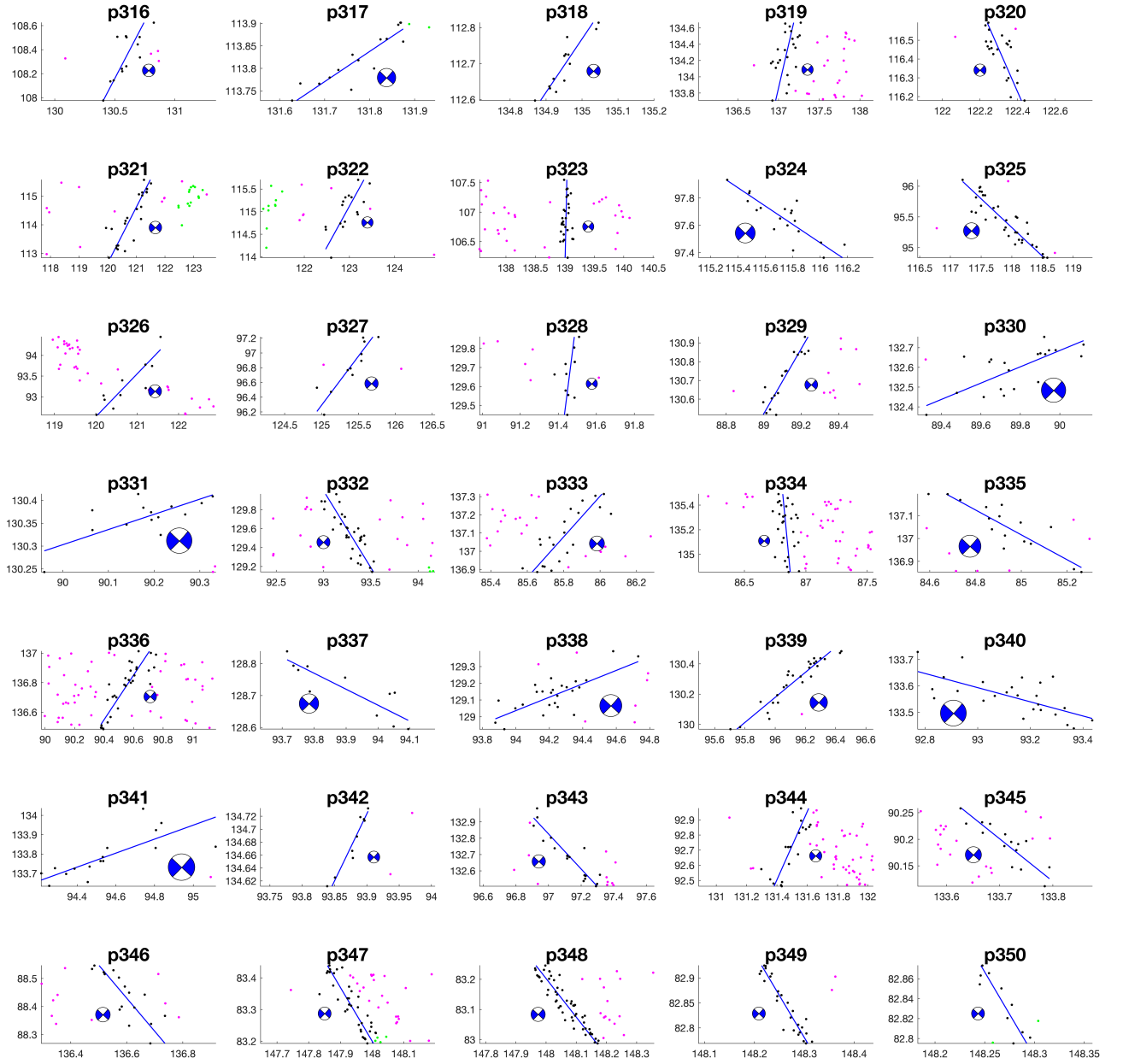
**Figure S11.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



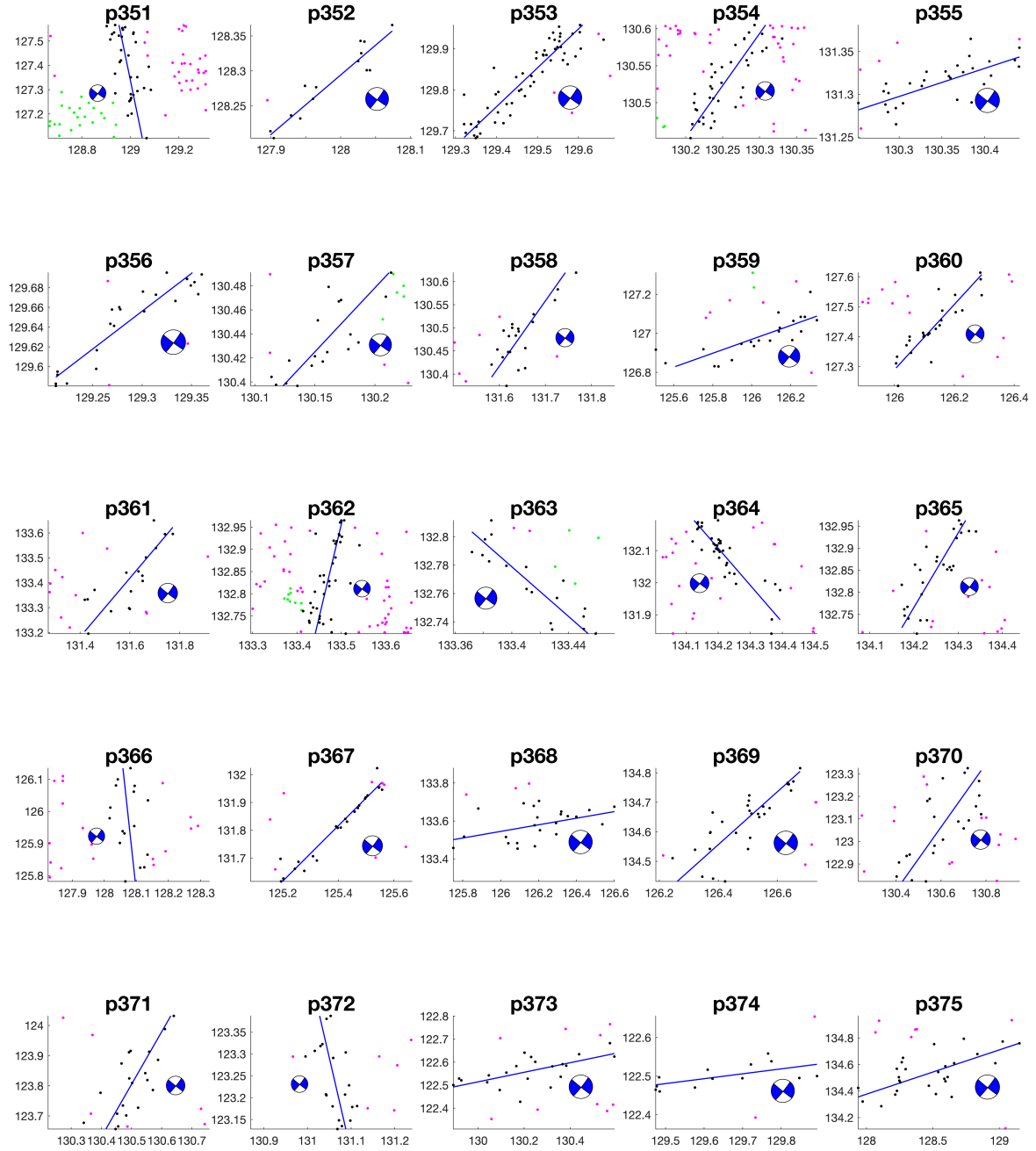
**Figure S12.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



**Figure S13.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



**Figure S14.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.



**Figure S15.** Close-up views of selected quasi-linear clusters. Each panel shows a quasi-linear cluster (black dots), along with a composite focal mechanism (blue beach ball). Solid blue line denotes a best-fit line segment. Magenta dots denote background seismicity. Green dots denote other selected quasi-linear clusters.