Supplementary materials for "The imbricated foreshock and aftershock activities of the Balsorano (Italy) M_w 4.4 normal fault earthquake and implications for earthquake initiation"

H. S. Sánchez-Reyes[1], D. Essing[1], E. Beaucé[2], P. Poli[11]

[1]*Institute of Earth Sciences, University Grenoble Alpes, Grenoble* 38100*, France*

[2]*Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, United States*

[*]*Corresponding author: hugo.sanchez-reyes@univ-grenoble-alpes.fr*

Contents of this file

1. Tables S1 to S4

2. Figures S1 to S2

Additional Supporting Information

1. Seismic catalog for the seismic sequence associated to the 2019 (M_W 4.4) Balsorano earthquake

Table S1: General information of the 2019 M_w 4.4 Balsorano earthquake. All this information is taken from the INGV's online catalog.

Mainshock data	
Magnitude	M_w 4.4
Lat () / Lon ()	13.61 / 41.78
Depth (km)	14.0
NP1: Strike / Dip / Rake	299 / 58 / -120
NP2: Strike / Dip / Rake	166 / 42 / -51
Reported activity	$\approx$ 150 events
# Stations < 100 km	6

Table S2: Receiver locations. The distances reported are measured with respect to the mainshock epicentral location (taken from the INGV).

Receiver	Lon. (^{o})	Lat. (^{o})	Dist. (km)
CERT	41.94903	12.98176	72.297
GUAR	41.79450	13.31229	33.093
INTR	42.01154	13.90460	41.820
POFI	41.71743	13.71202	13.112
PTQR	42.02193	13.40057	35.780
VVLD	41.86965	13.62324	10.411

Table S3: Velocity model used for the relocation process. A V_P/V_S ratio equal to 1.73 is assumed. Slightly modified version from the model proposed by Bagh et al. (2007)

Depth of top of layer (km)	P-wave velocity (km/s)
0.0	5.360
3.0	5.360
6.0	5.800
14.0	6.650
25.0	6.900

Table S4: Reference templates and phase traveltimes at the six available stations (estimated from INGV data).

#	Origin time	P_{tt} CERT	P_{tt} GUAR	P_{tt} INTR	P_{tt} POFI	P_{tt} PTQR	P_{tt} VVLD	S_{tt} CERT	S_{tt} GUAR	S_{tt} INTR	S_{tt} POFI	S_{tt} PTQR	S_{tt} VVLD
1	11/07/2019 00:37:18	9.63	5.51	6.9	3.46	6.37	3.48	17.09	9.11	11.95	5.82	11.28	5.71
2	11/07/2019 03:21:00	9.72	5.38	6.92	3.57	6.62	3.57	17.15	9.4	12.12	5.87	11.36	5.82
3	11/07/2019 10:37:05	9.69	5.39	6.93	3.7	6.52	3.54	17.15	9.15	12.05	6.00	11.38	5.82
4	11/07/2019 17:35:21	9.7	5.38	7.01	3.54	6.48	3.59	17.22	9.02	12.12	5.89	11.52	5.92
5	11/07/2019 17:47:53	9.77	5.4	6.93	3.32	6.53	3.55	17.29	9.12	12.07	5.45	11.42	5.68
6	11/07/2019 18:04:55	9.74	5.35	6.9	3.39	6.54	3.49	17.21	9.12	11.86	5.68	11.45	5.72
7	11/07/2019 23:19:50	9.62	5.29	7.09	3.54	6.44	3.55	16.89	8.99	12.19	6.00	11.20	5.79
8	11/08/2019 03:08:06	9.06	5.14	7.06	3.56	6.45	3.42	16.85	8.76	12.21	5.85	11.08	5.58
9	11/08/2019 08:10:56	9.93	5.56	6.75	3.17	6.72	3.37	17.33	9.23	11.69	5.39	11.58	5.48
10	11/08/2019 08:16:10	9.84	5.44	6.88	3.44	6.51	3.54	17.40	9.49	12.00	5.76	11.53	5.71
11	11/08/2019 10:43:24	9.50	5.15	6.89	3.32	6.29	3.38	17.00	8.91	12.08	5.78	11.19	5.61
12	11/08/2019 12:00:43	9.75	5.44	7.04	3.34	6.61	3.55	17.29	9.13	12.44	5.70	11.35	5.77
13	11/08/2019 13:07:07	9.41	5.08	6.86	3.32	6.22	3.34	16.88	8.77	12.31	5.64	11.04	5.45
14	11/08/2019 14:22:12	9.52	5.14	6.92	3.39	6.48	3.38	16.99	8.79	12.39	5.69	11.19	5.56
15	11/09/2019 10:57:09	9.72	5.35	6.87	3.21	6.54	3.46	17.20	9.03	11.98	5.52	11.33	5.70
16	11/09/2019 22:14:15	9.59	5.27	6.66	3.24	6.43	3.14	17.07	9.04	11.61	5.33	10.91	5.04
17	11/09/2019 23:09:52	9.79	5.49	6.90	3.62	6.61	3.59	17.48	9.12	11.88	5.69	11.66	5.91
18	11/10/2019 03:31:36	9.55	5.15	6.58	3.51	6.37	3.42	16.82	8.68	12.21	5.79	11.07	5.55
19	11/10/2019 06:56:28	9.62	5.15	6.56	3.15	6.40	3.07	17.04	9.04	11.92	5.42	11.39	5.09
20	11/11/2019 01:43:21	9.59	5.31	6.90	3.44	6.42	3.53	18.00	9.27	12.05	5.25	11.44	5.76
21	11/11/2019 13:41:33	9.46	5.11	7.00	3.49	6.22	3.39	16.81	8.79	12.20	5.85	11.10	5.54
22	11/11/2019 16:04:53	9.39	5.05	6.95	3.43	6.25	3.34	17.07	8.70	12.27	5.75	11.08	5.52
23	11/11/2019 17:46:53	9.61	5.22	6.86	3.32	6.40	3.43	17.05	8.97	12.44	5.22	11.23	5.62

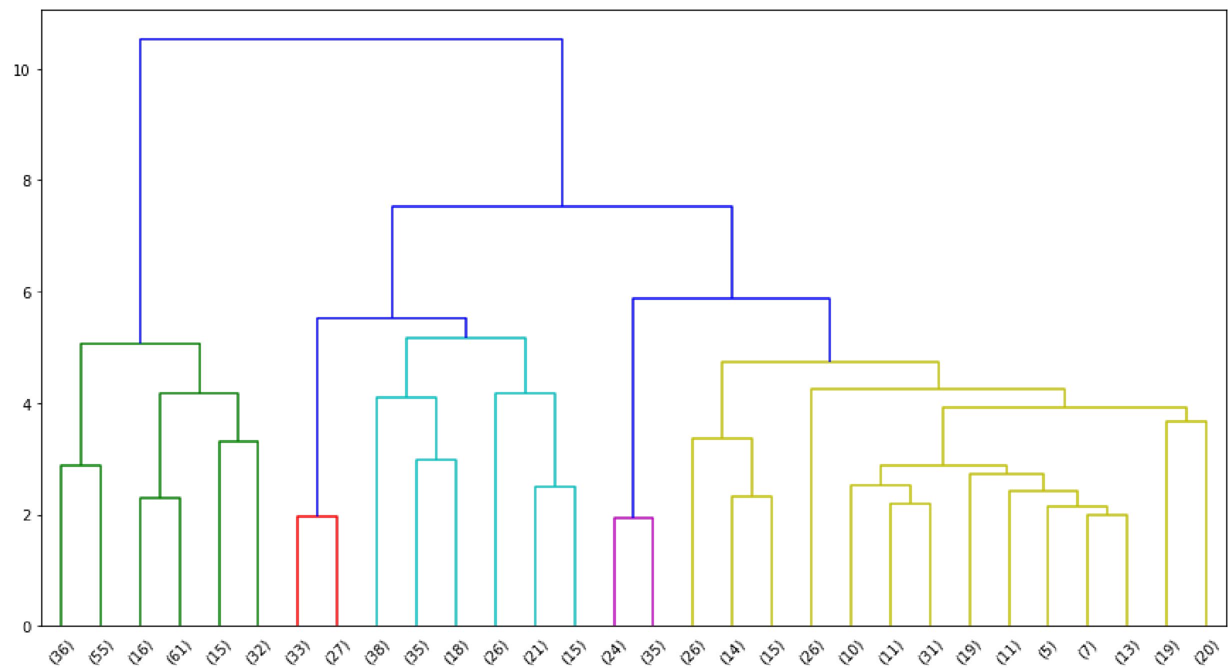

Figure S1: Dendrogram obtained from the waveform-based hierarchical clustering performed. The distance metric between two different waveforms (i and j) is estimated as 1-C_{ij}. Ward's minimum variance linkage technique is used. The distance threshold to define the final number of cluster is set to 5.3 (the largest separation observed form dendrogram).

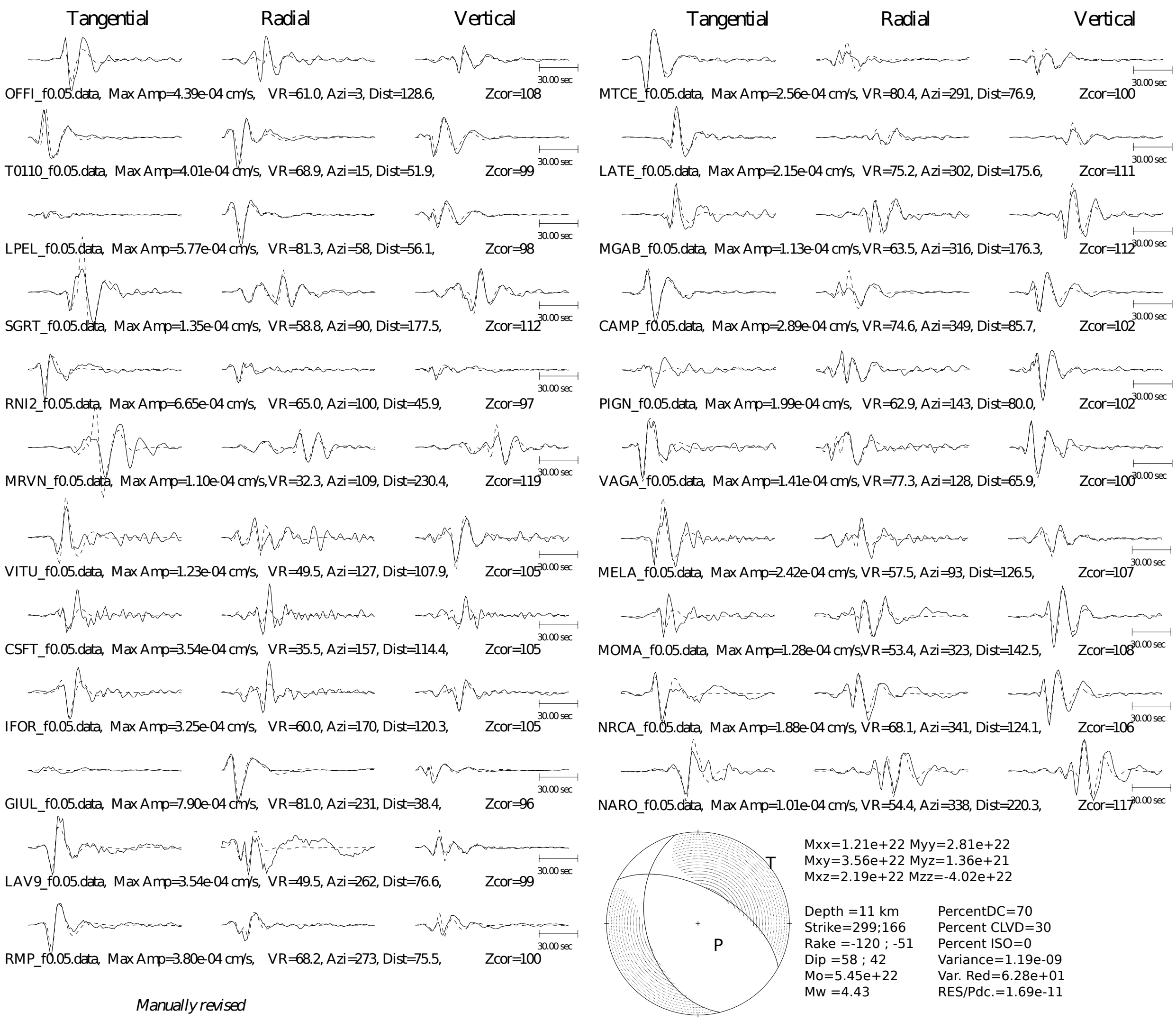

Figure S2: Estimated focal mechanism and comparison of observed (solid lines) and estimated synthetic seismograms (dashed lines) for the Mw 4.4 mainshock. The three components at 22 receiver locations are shown. This figure is a modified version from the original one provided by the INGV (http://webservices.ingv.it/webservices/ingv_ws_map/data/tdmt/15111/73711301_86_tdmt_reviewer_solution.pdf).

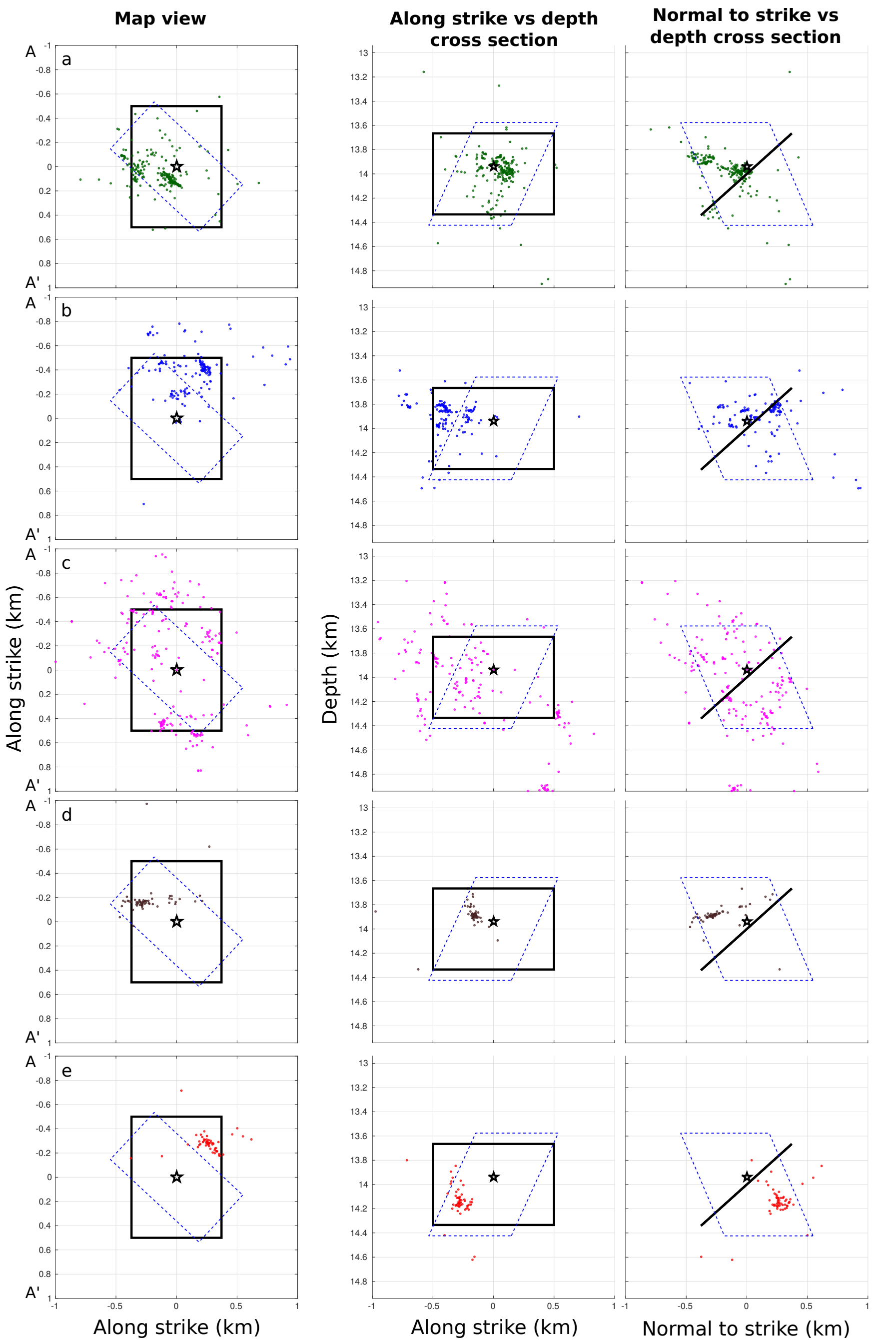

Figure S3: Map view (left column), and cross-sections along the strike (middle column) and normal-strike (right column) directions for each of the five clusters identified in the sequence (as indicated). All of the locations are relative to the mainshock hypocenter (41.7746^{o}N 13.6066^{o}E; 13.94 km depth, black star). In all of the panels, the same color code is used as in Figures 3 and 4 to represent each different cluster. The solid black line represents a fault plane of 1 km^2 with the geometry of the second nodal plane (Supplementary Materials Table S1). The directions A-A' (along strike) and B-B' (normal to the strike) are the same as in Figure 1. Each cluster is represented by a correponding label a) Cluster 1 , b) Cluster 2, c) Cluster 3, d) Cluster 4 and e) Cluster 5. The blue dashed line represent the assumed auxilary plane.

References

Bagh, S., Chiaraluce, L., De Gori, P., Moretti, M., Govoni, A., Chiarabba, C., Di Bartolomeo, P., and Romanelli, M. (2007). Background seismicity in the central apennines of italy: The abruzzo region case study. *Tectonophysics*, 444(1-4):80–92.