

Supplementary material for

Seismological evidence for fluid accumulation beneath the dormant East Eifel volcanic region, Germany

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This document includes six additional figures (Figs. S1 to S10) and one table (Table S1), which complements the main manuscript.

Fig. S1 gives an example of InSAR and GNSS-derived ground motions close to the village Ochtendung, showing that short-term transients (e.g., vertical or east-west) are not observed across the Ochtendung Seismic Zone (OSZ).

Fig. S2 gives additional waveform examples for individual stations observing SxS phases after direct S-waves.

Fig. S3 shows complementary examples of record sections under different alignment strategies.

Fig. S4 presents theoretical SxS reflection coefficients as a function of distance (incidence angle) and impedance contrast of the reflector.

Fig. S5 shows synthetic waveforms calculated for station TB112 and an earthquake in cluster C2. While different impedance contrasts were tested, the given example relates to a reflector bearing high fluid content.

Fig. S6 gives examples of waveform sections for a microearthquake from cluster C2 at a number of additional stations.

Fig. S7 shows that seismic waveforms recorded at stations near the Laacher See Volcano (LSV) have long coda waves, indicating strong scattering and attenuation.

Fig. S8 shows the geographic distribution of the average Power Spectral Density (PSD) for the Eifel Large-N seismic network.

Fig. S9 presents two additional burst-like microearthquake sequences recorded at station TB112.

Fig. S10 provides information on the residuals from the imaging procedure to locate mid-crustal scatterers.

At last, Table S1 gives the catalog of the microearthquakes used for imaging.

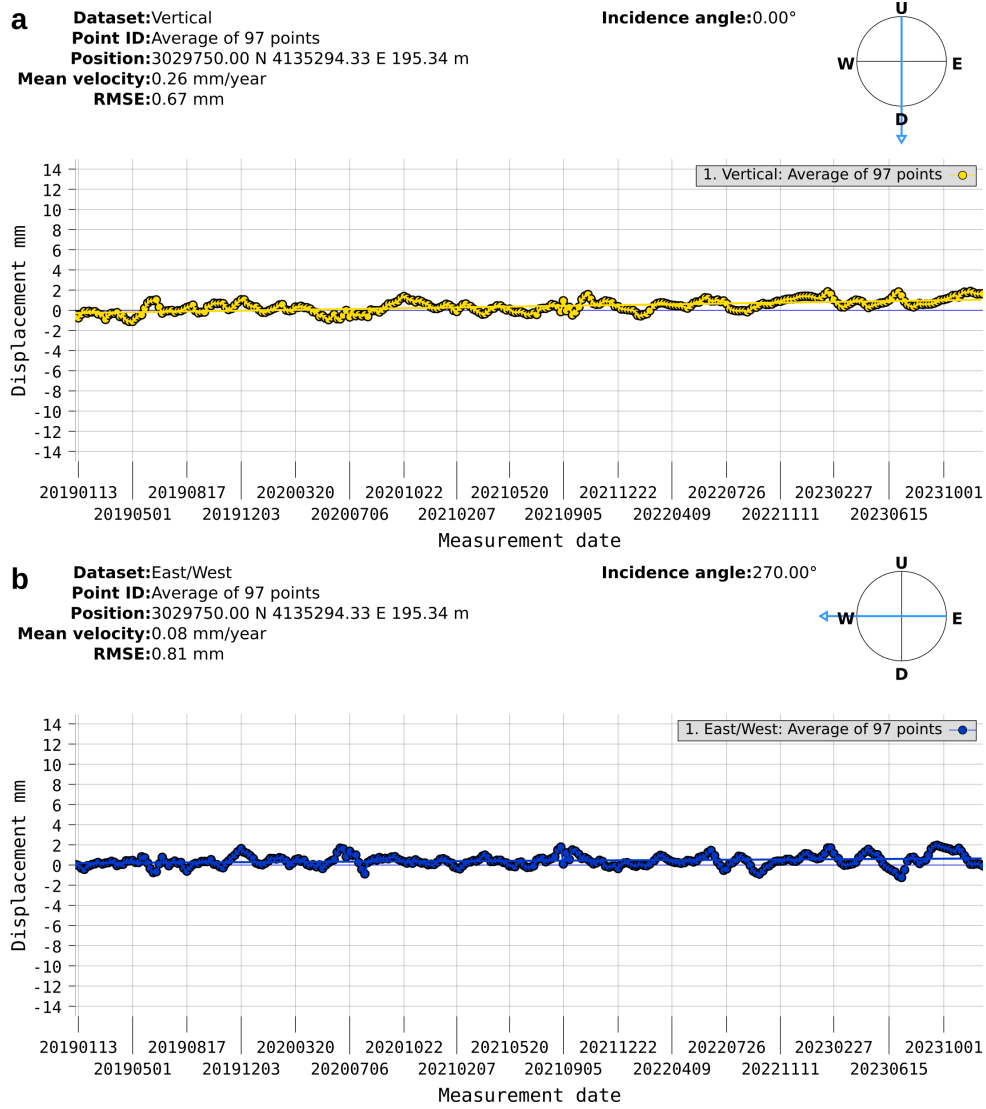


Fig. S1 Time series of ground displacement between January 2019 and November 2023 at Ochten-dung derived from the European Ground Motion Service (EGMS) Ortho products. Panels show the mean displacement averaged over 97 points at Ochten-dung in (a) the vertical and (b) the east–west directions. Both components show only minor fluctuations around zero, indicating negligible vertical (0.26 mm/year) and horizontal (0.08 mm/year) ground deformation in this area. These values are very small within the uncertainty range, indicating no pronounced vertical or strike-slip deformation.

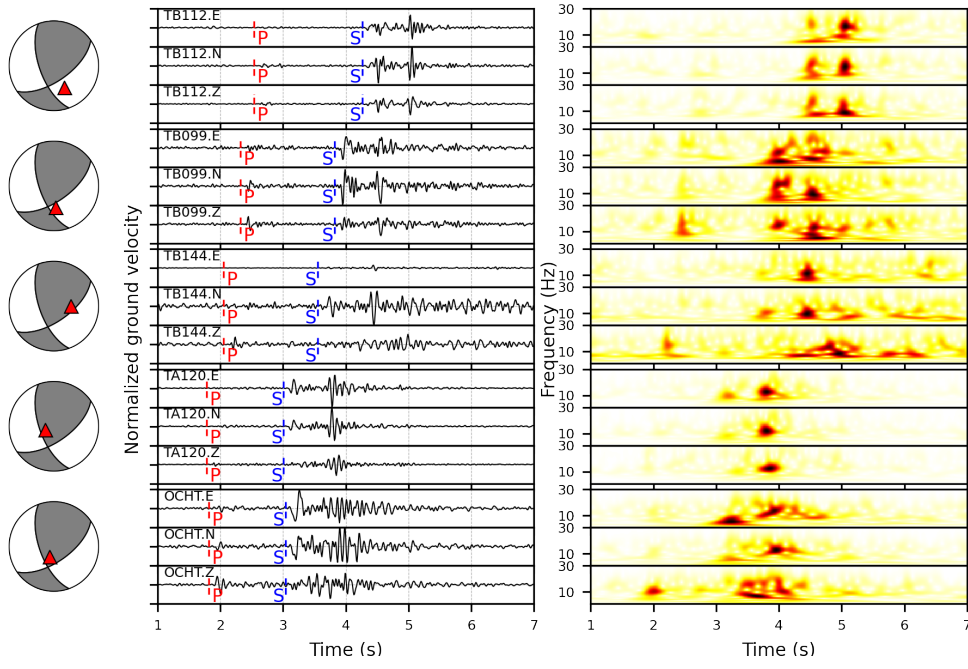


Fig. S2 Waveforms of all three components for the same stations as shown in Fig. 1e and f are presented. The left column displays the focal mechanisms (beach balls), with a red triangle marking the P-wave takeoff direction toward each station. The middle column shows waveforms normalized at each station, while the right column presents the corresponding time–frequency spectra.

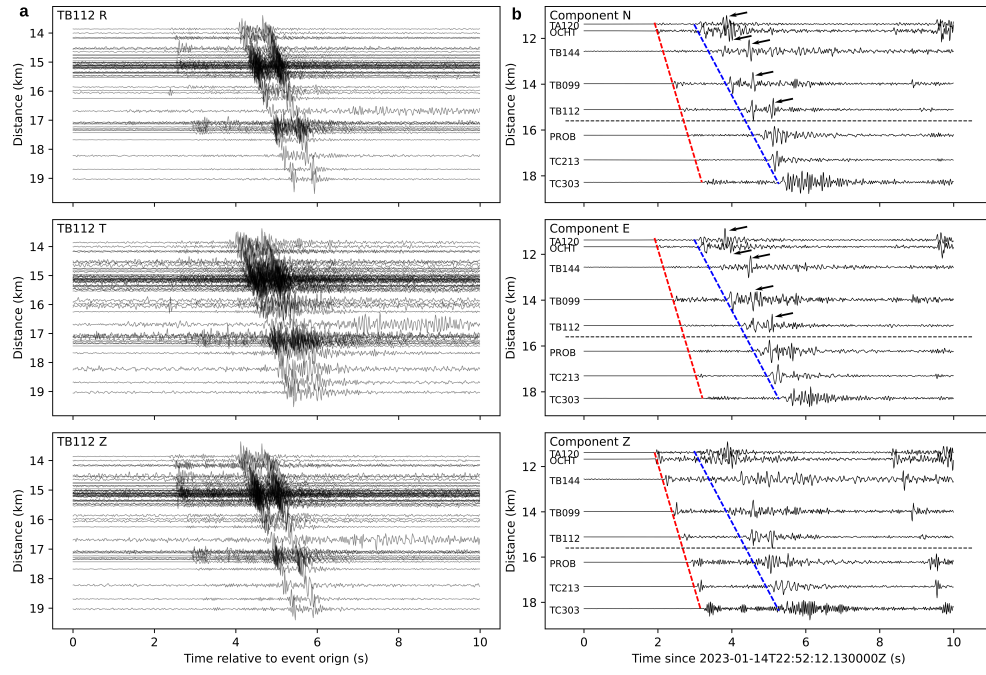


Fig. S3 Examples of record sections under two alignment strategies. (a) Waveform sections of different events within the Ochtendung Seismic Zone (OSZ) recorded at station TB112 for the R, T, and Z components. (b) Waveforms of a single event aligned across multiple stations for the N, E, and Z components. Red and blue dashed lines indicate the direct P- and S-wave arrivals, respectively. At source-receiver distances greater than 16 km, only the direct S wave is observed, arguing against SP phases and also suggesting that the reflectors are localized.

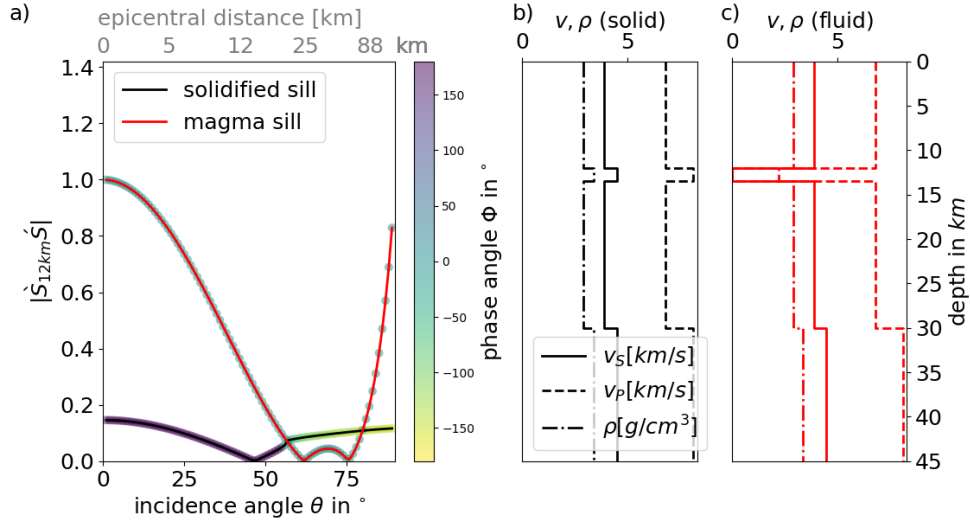


Fig. S4 (a) Reflection coefficient curves for the solid and fluid beneath the interface, respectively, showing that the fluid produces strong reflections, whereas the solid does not. (b) and (c) show the corresponding velocity and density models for the solid and fluid sill cases, respectively.

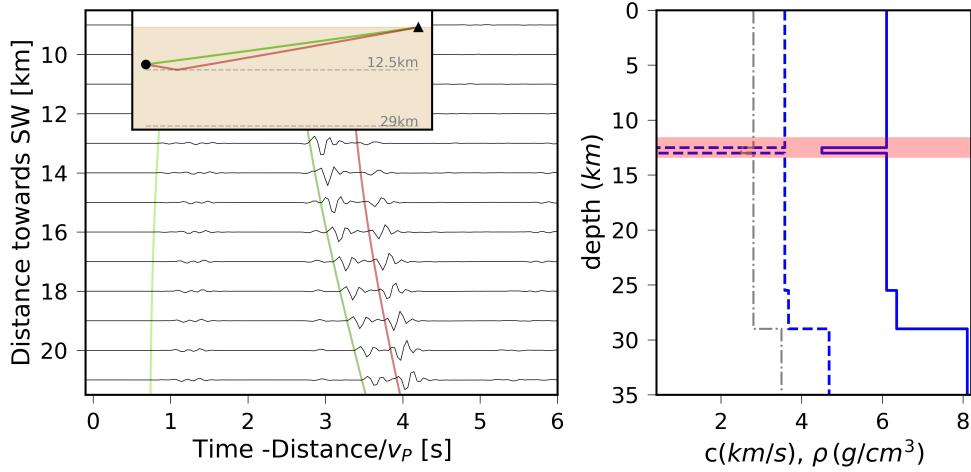


Fig. S5 Synthetic waveform test for the C2 events recorded at station TB112. The synthetic waveforms show a good overall agreement with the observations. The waveform fidelity is controlled by several key parameters, including the source-receiver distance, source depth, reflector geometry and dip, radiation pattern, and the impedance contrast at the reflecting boundary. We filtered synthetic seismograms between 5 and 7 Hz. Given the current limitations, only a simple layer is used to generate the reflected waves (right panel). For the given layered 1D model, a double couple source with a strike of 175°, a dip of 80°, and a rake of -60° was used. Seismograms represent ground velocity.

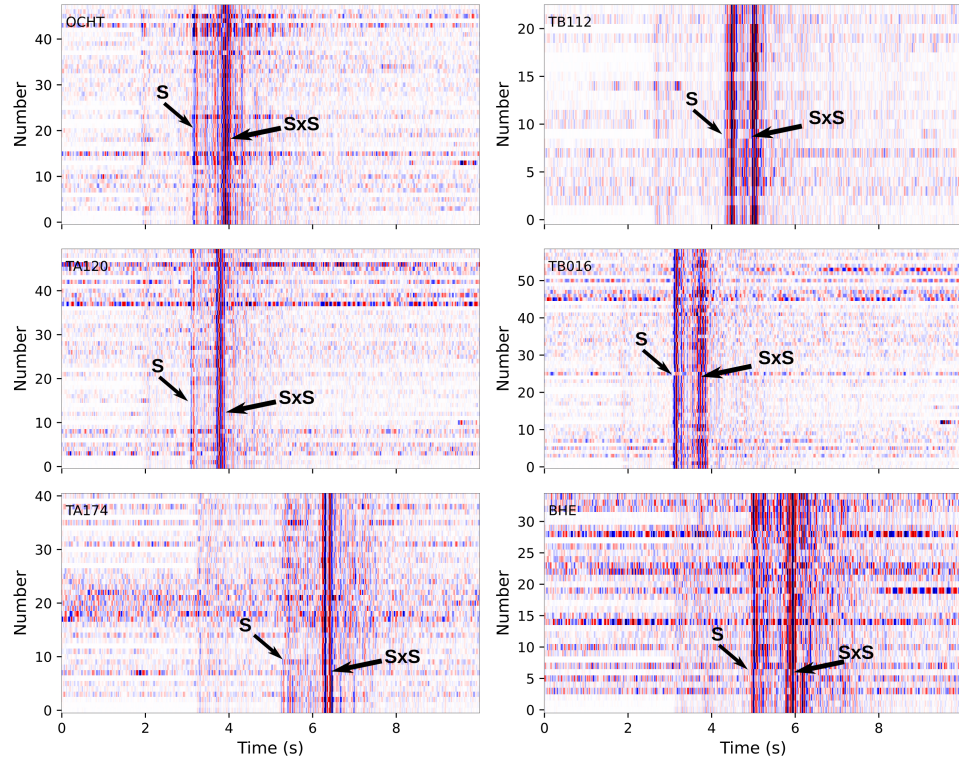


Fig. S6 Examples of the waveform sections for the microearthquake cluster C2, shown for the other stations (OCHT, TB112, TA120, TB016, TA174, and BHE).

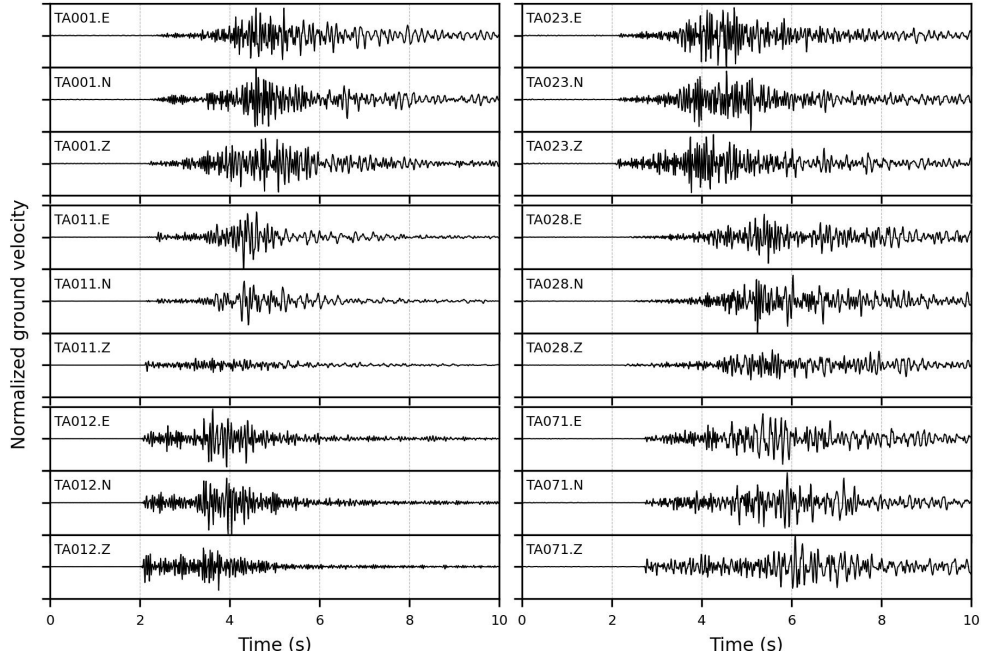


Fig. S7 Examples of seismic waveforms recorded at stations near LSV, with long coda waves indicating strong scattering and attenuation.

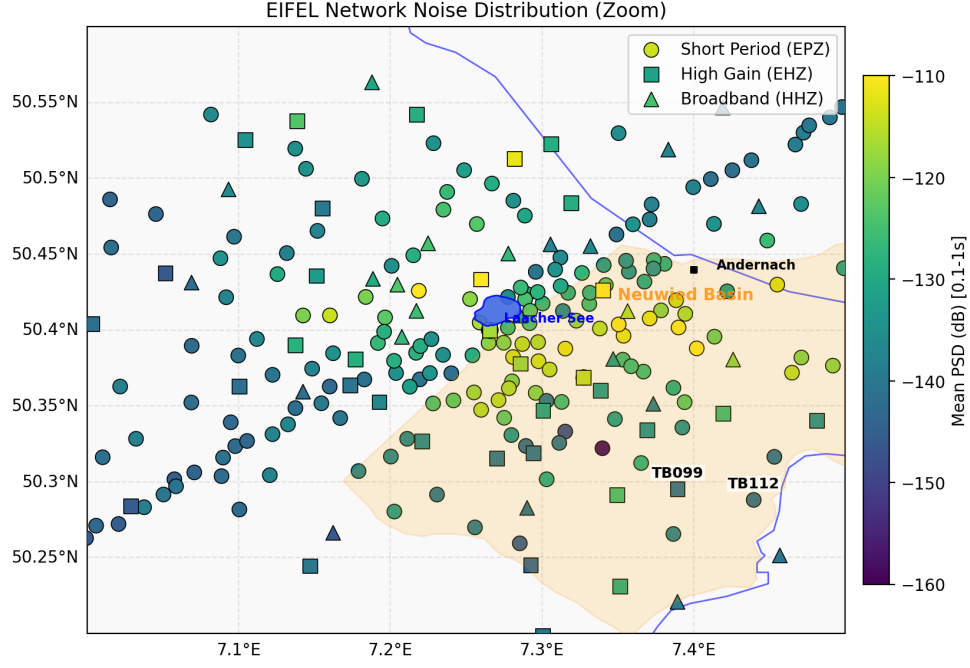


Fig. S8 Average Power Spectral Density (PSD) for the Eifel seismic network within the 0.1-1.0 s period band. Color coding represents noise levels in decibels (dB), with darker colors indicating lower ambient noise. The Neuwied Basin is outlined in yellow, and the blue polygon highlights Laacher See. Station markers distinguish between broadband (HHZ), high-gain (EHZ), and short-period (EPZ) instruments. Specific stations within the volcanic Eifel region used for seismic analysis in the main text are labeled.

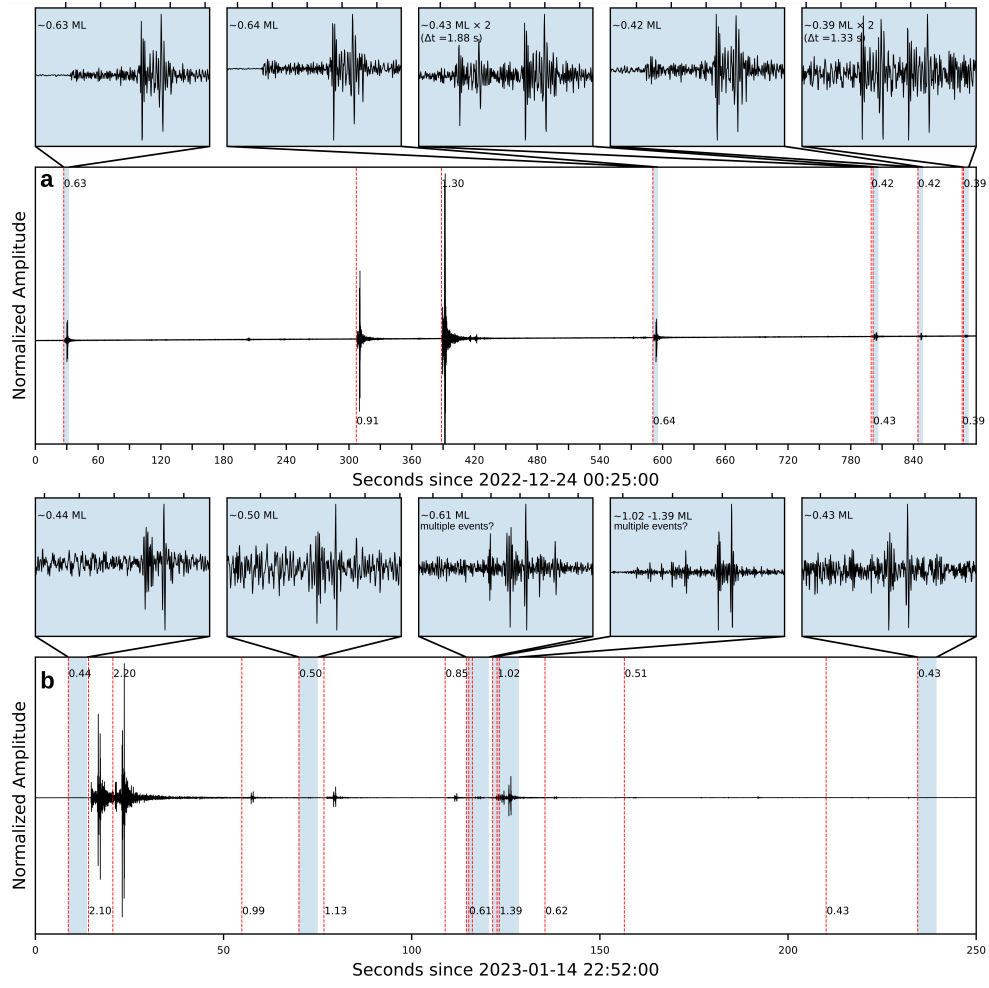


Fig. S9 Two additional burst-like microearthquake sequences recorded at station TB112, shown in the same format as Fig. 2g. Panel (a) shows a burst located outside cluster C2, whereas panel (b) shows a burst within the same cluster C2 as Fig. 2g. Red dashed lines mark detected events, and insets display zoomed waveforms of the shaded events.

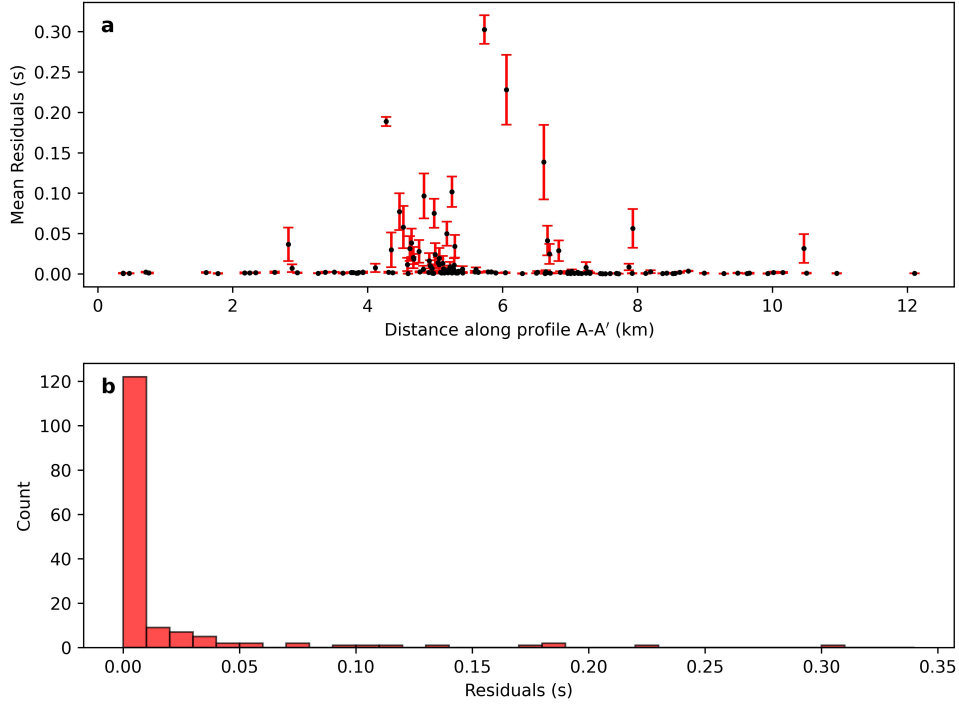


Fig. S10 (a) Mean Δt residuals of the earthquakes shown in Fig. 3e, plotted as a function of the projected distance along profile A–A', with error bars indicating variability. Most events cluster close to zero, with a few outliers reaching up to ~ 0.3 s. (b) Histogram of residuals for all the events, with the majority of values concentrated near zero.

Table S1: Catalog of the microearthquakes used for imaging

No.	time	latitude	longitude	depth (km)	magnitude (M_L)
1	2022-09-24 17:41:29.980000	50.3710	7.3776	10.91	1.90
2	2022-09-24 17:43:24.130000	50.3725	7.3762	10.56	0.90
3	2022-09-24 17:44:23.510000	50.3715	7.3759	10.90	0.70
4	2022-09-24 17:48:25.870000	50.3701	7.3736	10.60	0.50
5	2022-09-24 17:51:51.210000	50.3713	7.3769	10.91	0.50
6	2022-09-24 17:53:26.940000	50.3730	7.3719	10.90	0.50
7	2022-09-25 04:59:34.250000	50.3973	7.3439	12.96	0.50
8	2022-09-25 05:00:23.590000	50.3959	7.3451	12.65	0.50
9	2022-09-26 23:03:14.140000	50.3601	7.3858	11.05	0.70
10	2022-09-27 19:31:46.390000	50.3722	7.3774	10.50	0.90
11	2022-09-28 17:13:00.280000	50.3556	7.3943	12.64	0.70
12	2022-10-01 12:27:31.270000	50.3661	7.3836	10.04	0.80
13	2022-10-08 20:46:11.960000	50.3504	7.3941	12.58	0.60

14	2022-10-11 14:32:39.110000	50.3432	7.4116	13.68	0.80
15	2022-10-11 22:33:02.350000	50.3712	7.3767	11.23	0.60
16	2022-10-13 23:36:20.340000	50.3779	7.3680	10.66	0.40
17	2022-10-16 00:12:19.610000	50.3551	7.3487	5.77	0.70
18	2022-10-18 00:08:00.260000	50.3777	7.3757	11.73	0.60
19	2022-10-18 16:06:15.120000	50.3778	7.3683	11.39	0.70
20	2022-10-22 12:45:51.230000	50.3502	7.3766	12.19	0.90
21	2022-10-28 18:10:36.430000	50.3495	7.3923	11.05	0.70
22	2022-10-29 02:32:38.590000	50.3581	7.3804	10.84	0.50
23	2022-10-29 08:26:07.230000	50.3897	7.3583	11.49	0.80
24	2022-11-03 01:07:47.230000	50.3734	7.3715	11.20	0.80
25	2022-11-09 09:24:36.390000	50.3522	7.3826	11.34	1.00
26	2022-11-28 00:45:37.160000	50.3599	7.3931	12.58	0.80
27	2022-11-29 12:21:55.280000	50.3725	7.3797	11.15	0.80
28	2022-12-03 12:29:28.780000	50.3451	7.3977	11.98	0.70
29	2022-12-06 09:37:14.840000	50.3547	7.3486	5.91	0.70
30	2022-12-10 16:52:54.350000	50.4037	7.3363	12.06	0.60
31	2022-12-10 16:53:33.560000	50.4035	7.3369	12.10	0.60
32	2022-12-10 22:24:55.950000	50.3212	7.4317	11.67	0.70
33	2022-12-16 22:40:57.810000	50.3577	7.3909	11.78	0.60
34	2022-12-17 21:06:50.110000	50.3330	7.4178	11.53	0.70
35	2022-12-18 19:51:55.730000	50.3892	7.3558	10.78	0.80
36	2022-12-22 03:13:22.530000	50.3304	7.4240	12.63	1.00
37	2022-12-22 21:43:54.120000	50.3748	7.3692	11.59	0.80
38	2022-12-24 00:25:25.210000	50.3814	7.3619	12.65	1.00
39	2022-12-24 00:30:05.000000	50.3820	7.3626	12.72	1.00
40	2022-12-24 00:31:26.440000	50.3819	7.3648	12.90	1.30
41	2022-12-24 00:34:48.780000	50.3801	7.3625	12.72	0.90
42	2022-12-24 00:38:19.300000	50.3801	7.3625	12.72	0.90
43	2022-12-24 00:39:02.360000	50.3811	7.3632	12.44	0.90
44	2022-12-24 11:33:23.860000	50.3841	7.3643	12.54	0.90
45	2023-01-03 01:59:19.610000	50.3443	7.3914	11.80	0.70
46	2023-01-03 03:20:43.120000	50.3683	7.3847	12.51	0.60
47	2023-01-07 05:40:38.060000	50.3715	7.3731	10.97	0.80
48	2023-01-14 22:52:12.130000	50.3731	7.3779	10.93	2.10
49	2023-01-14 22:52:18.560000	50.3725	7.3768	11.00	2.20
50	2023-01-14 22:52:52.790000	50.3724	7.3747	11.22	1.00
51	2023-01-14 22:53:14.720000	50.3707	7.3779	11.31	1.00
52	2023-01-14 22:53:46.940000	50.3722	7.3779	11.36	0.90
53	2023-01-14 22:54:01.310000	50.3721	7.3768	11.01	1.10
54	2023-01-14 22:57:28.290000	50.3723	7.3725	10.71	0.90
55	2023-01-14 22:58:28.540000	50.3701	7.3747	10.79	0.80
56	2023-01-14 23:00:52.090000	50.3720	7.3769	11.05	0.90
57	2023-01-14 23:05:09.780000	50.3730	7.3783	11.28	1.10
58	2023-01-14 23:12:54.500000	50.3728	7.3796	11.58	0.90

59	2023-01-14 23:14:57.730000	50.3756	7.3818	10.90	0.80
60	2023-01-14 23:31:51.810000	50.3715	7.3781	11.18	0.90
61	2023-01-21 19:10:54.510000	50.3573	7.3902	11.75	0.70
62	2023-01-24 04:28:13.710000	50.3437	7.4179	13.00	0.70
63	2023-01-24 14:41:54.540000	50.3904	7.3535	12.84	0.80
64	2023-01-29 09:52:51.000000	50.3496	7.3766	12.30	1.20
65	2023-01-30 22:26:05.550000	50.3570	7.3905	11.74	0.80
66	2023-02-01 11:20:16.340000	50.4072	7.3359	13.07	1.10
67	2023-02-01 11:26:22.920000	50.4079	7.3375	12.80	1.00
68	2023-02-02 20:54:30.730000	50.3786	7.3686	11.70	0.80
69	2023-02-04 01:29:06.130000	50.3502	7.3987	12.53	0.80
70	2023-02-05 00:10:34.670000	50.3478	7.3533	5.72	0.60
71	2023-02-05 00:19:16.060000	50.3467	7.3510	5.44	0.70
72	2023-02-05 04:14:18.680000	50.3680	7.3775	11.26	0.60
73	2023-02-05 04:15:24.670000	50.3689	7.3787	11.71	0.70
74	2023-02-11 21:13:05.920000	50.3732	7.4454	7.55	0.70
75	2023-02-17 01:14:23.330000	50.3668	7.3784	11.07	0.70
76	2023-02-18 23:42:07.210000	50.3641	7.3786	11.72	0.70
77	2023-02-20 00:09:47.270000	50.3559	7.3904	11.52	0.80
78	2023-02-22 00:03:11.480000	50.3531	7.3945	13.95	0.60
79	2023-02-25 19:47:15.510000	50.4130	7.3943	13.32	0.80
80	2023-03-02 22:48:09.070000	50.3555	7.3948	14.82	0.70
81	2023-03-08 06:17:03.280000	50.3610	7.3912	11.07	1.00
82	2023-03-11 04:22:02.690000	50.3857	7.3588	12.70	0.80
83	2023-03-15 21:51:50.990000	50.3325	7.4176	11.78	0.90
84	2023-03-16 00:54:06.630000	50.3718	7.3805	12.43	0.90
85	2023-03-16 02:01:03.990000	50.3450	7.3945	12.72	0.90
86	2023-03-17 04:55:25.120000	50.3600	7.3960	12.31	1.00
87	2023-03-20 01:46:52.560000	50.3612	7.3866	11.72	0.70
88	2023-03-20 20:42:00.090000	50.3743	7.3775	11.82	0.70
89	2023-03-20 20:42:07.320000	50.3749	7.3789	11.65	0.70
90	2023-03-20 20:46:15.300000	50.3749	7.3797	11.95	0.80
91	2023-04-08 07:01:49.570000	50.4077	7.3393	12.88	0.80
92	2023-04-10 11:04:10.890000	50.3550	7.3719	10.90	0.90
93	2023-04-14 06:18:52.420000	50.3681	7.3826	12.70	0.90
94	2023-04-15 17:48:06.530000	50.3540	7.3973	12.95	0.80
95	2023-04-16 20:00:09.350000	50.3557	7.3964	12.12	0.70
96	2023-04-18 01:19:36.290000	50.3591	7.3903	11.44	0.70
97	2023-04-19 19:18:51.110000	50.3858	7.3617	11.87	0.80
98	2023-04-19 21:51:59.480000	50.3746	7.3745	11.81	0.70
99	2023-04-25 12:00:03.110000	50.3506	7.3744	12.90	0.90
100	2023-04-25 18:56:26.570000	50.3577	7.3895	11.52	0.80
101	2023-04-26 00:01:00.870000	50.3730	7.3783	11.06	0.80
102	2023-04-26 00:08:48.890000	50.3744	7.3762	10.71	0.70
103	2023-04-26 22:13:43.320000	50.3363	7.4176	12.34	0.90

104	2023-04-27 00:44:48.460000	50.3377	7.4173	12.07	0.70
105	2023-04-28 20:37:37.810000	50.3737	7.3796	11.10	0.70
106	2023-04-28 21:25:10.980000	50.3684	7.3807	9.96	0.70
107	2023-05-02 03:56:32.210000	50.3800	7.3709	10.31	0.70
108	2023-05-06 18:02:03.660000	50.3628	7.3871	11.98	0.70
109	2023-05-06 22:49:21.500000	50.3419	7.3954	14.17	0.60
110	2023-05-10 01:31:01.940000	50.3737	7.3702	12.56	0.70
111	2023-05-11 04:05:28.280000	50.3465	7.4028	11.89	0.80
112	2023-05-16 17:30:23.610000	50.3765	7.3769	10.62	0.80
113	2023-05-22 22:20:02.450000	50.3745	7.3761	10.65	0.80
114	2023-05-23 12:07:17.060000	50.3821	7.3647	12.41	0.90
115	2023-05-27 08:32:28.100000	50.3405	7.4140	12.73	0.80
116	2023-05-27 08:33:20.640000	50.3415	7.4171	12.63	0.80
117	2023-05-27 18:07:25.860000	50.3751	7.3768	11.21	0.70
118	2023-05-27 18:11:09.430000	50.3731	7.3780	11.20	0.70
119	2023-05-27 18:11:26.350000	50.3741	7.3811	11.44	0.70
120	2023-05-29 12:04:42.080000	50.3753	7.3682	13.51	0.70
121	2023-05-30 07:57:17.160000	50.3366	7.4127	13.49	0.80
122	2023-06-03 01:54:46.020000	50.3398	7.3965	13.39	0.60
123	2023-06-03 12:30:47.190000	50.3729	7.3793	11.29	1.00
124	2023-06-08 03:30:39.180000	50.3547	7.3958	11.82	0.60
125	2023-06-09 10:39:42.940000	50.3506	7.4014	12.07	1.80
126	2023-06-09 10:42:38.710000	50.3473	7.4021	12.46	0.90
127	2023-06-17 06:54:08.830000	50.3645	7.3858	12.25	0.60
128	2023-06-20 09:26:11.640000	50.3510	7.3716	12.64	0.70
129	2023-06-21 15:01:36.310000	50.3620	7.3891	11.83	0.70
130	2023-06-21 15:19:31.380000	50.3634	7.3889	11.94	0.70
131	2023-06-21 23:58:15.510000	50.3568	7.3917	11.54	0.50
132	2023-06-24 18:06:28.030000	50.3479	7.4043	13.33	0.60
133	2023-06-24 22:04:57.810000	50.3606	7.3952	12.25	0.50
134	2023-07-02 07:46:45.020000	50.3527	7.3728	11.71	0.80
135	2023-07-10 01:06:11.090000	50.3707	7.3825	11.24	0.50
136	2023-07-12 01:08:01.670000	50.3930	7.3502	12.65	0.70
137	2023-07-12 03:59:08.270000	50.3525	7.3686	12.94	0.70
138	2023-07-12 04:00:03.520000	50.3929	7.3522	12.87	0.70
139	2023-07-12 05:29:12.560000	50.3885	7.3575	12.88	0.80
140	2023-07-14 08:02:26.470000	50.3861	7.3657	11.50	0.70
141	2023-07-17 22:32:58.920000	50.3740	7.3787	11.00	0.60
142	2023-07-19 08:11:50.810000	50.3779	7.3740	10.86	1.20
143	2023-07-21 06:15:56.030000	50.3729	7.3792	11.29	0.70
144	2023-07-31 08:45:47.060000	50.3739	7.3826	11.14	0.90
145	2023-08-01 13:42:53.280000	50.3746	7.3798	10.93	0.90
146	2023-08-04 11:57:18.040000	50.3763	7.3746	10.67	1.00
147	2023-08-04 11:59:15.020000	50.3753	7.3777	11.10	0.80
148	2023-08-04 12:31:22.960000	50.3772	7.3739	10.56	1.20

149	2023-08-04 12:32:22.920000	50.3777	7.3720	10.61	0.80
150	2023-08-04 12:44:53.690000	50.3784	7.3722	10.61	0.80
151	2023-08-05 00:31:54.560000	50.3736	7.3794	11.02	0.70
152	2023-08-05 10:19:35.120000	50.3592	7.3906	11.35	0.90
153	2023-08-05 22:09:33.880000	50.3806	7.3683	10.87	0.80
154	2023-08-09 15:06:48.360000	50.3595	7.3830	11.23	0.80
155	2023-08-10 04:09:51.420000	50.3744	7.3782	11.12	0.90
156	2023-08-11 00:42:22.720000	50.3783	7.3758	10.71	0.70
157	2023-08-14 02:15:49.740000	50.3751	7.3760	11.48	0.60
158	2023-08-14 02:23:28.720000	50.3755	7.3731	11.35	0.60
