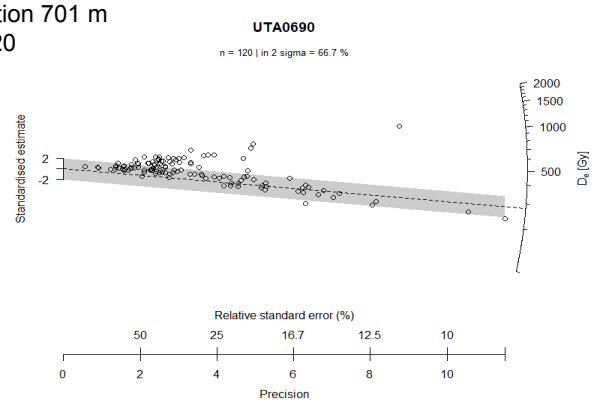
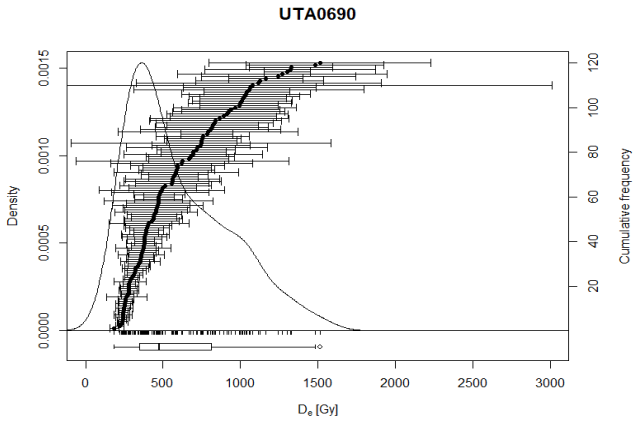
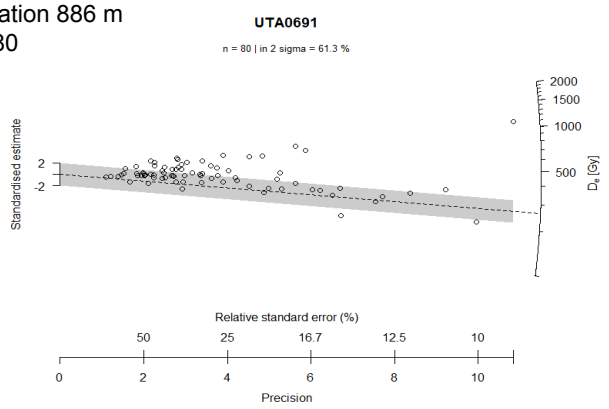
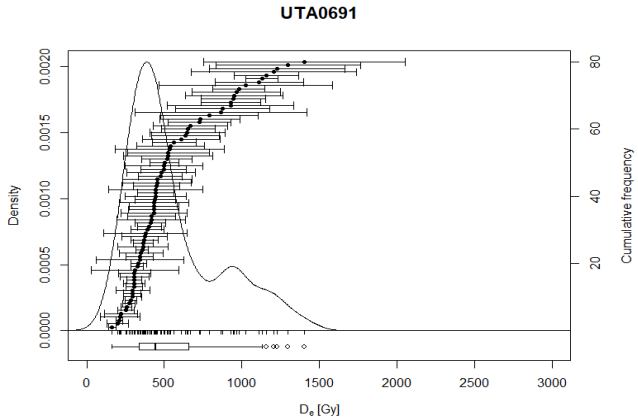
25MS-02
Elevation 701 m
n = 120



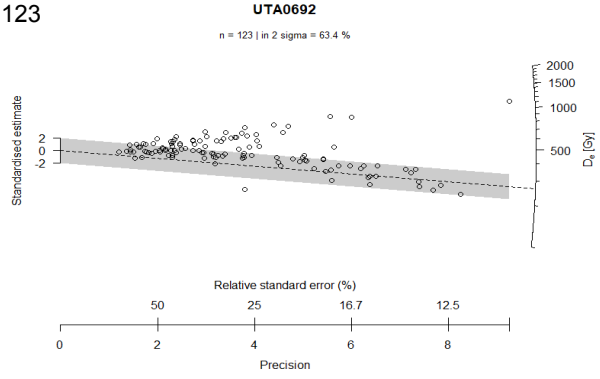


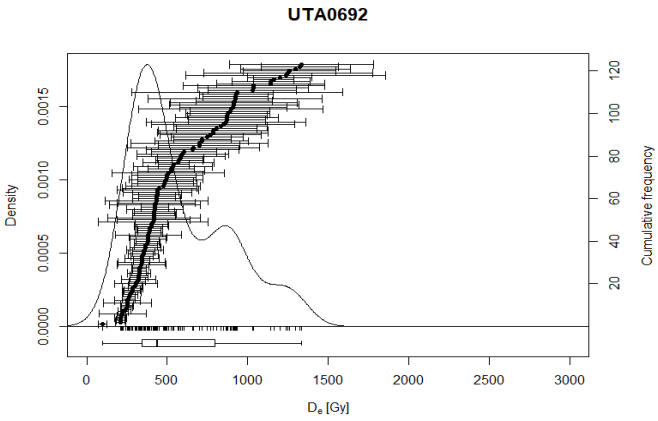
25MS-03
Elevation 886 m
n = 80





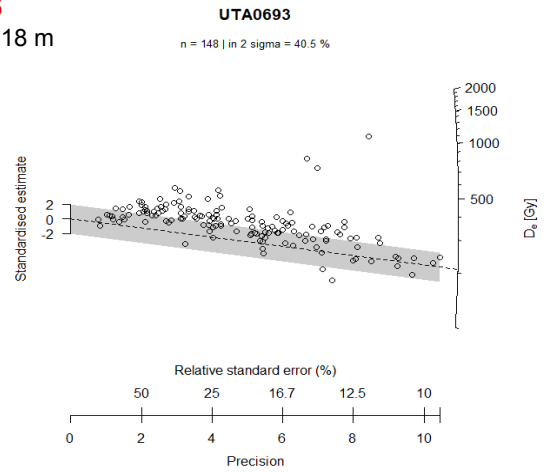
25MS-05
Elevation 597 m
n = 123

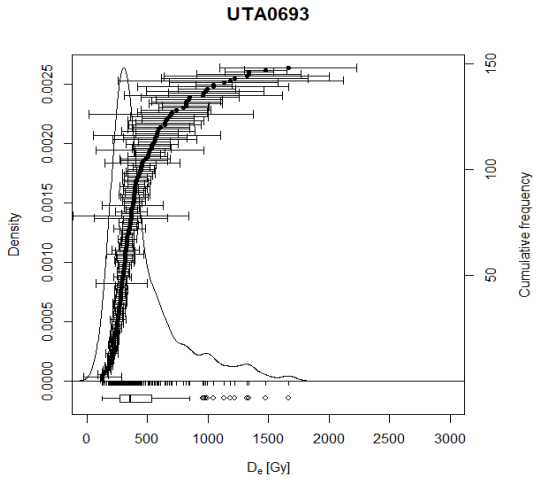




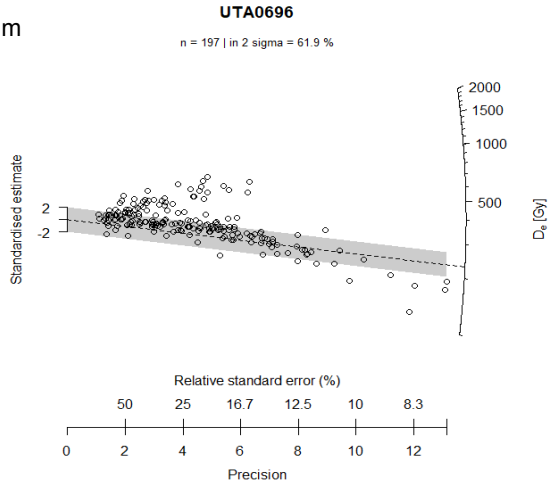
Extended Data Figure 1 | Radial plots (left) and KDE plots (right) for 3 of the 6 samples with resolved luminescence ages. KDE is kernal density estimate. Dashed line in the radial plots is the De value from the minimum age model, shaded gray area is ± 2σ error.

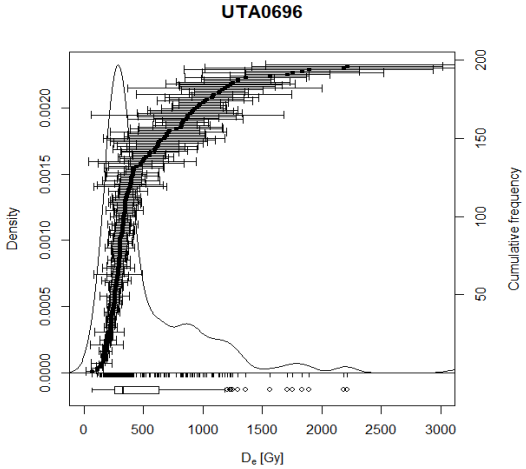
25MS-06
Elevation 118 m
n = 148



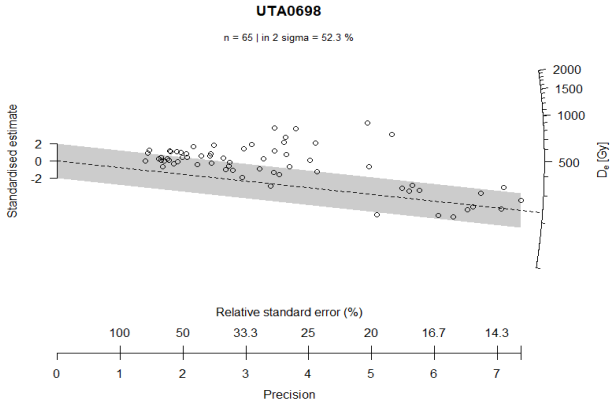


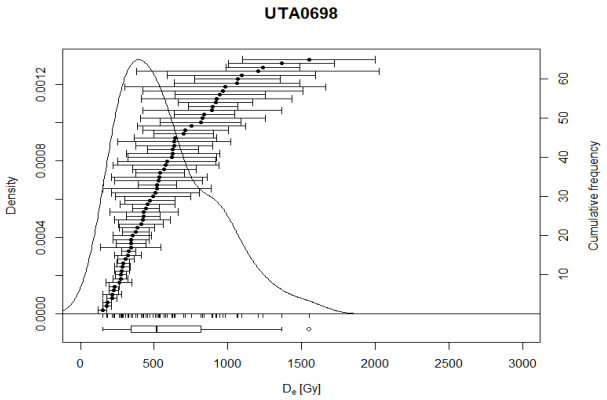
25MS-09
Elevation 955 m
n = 197





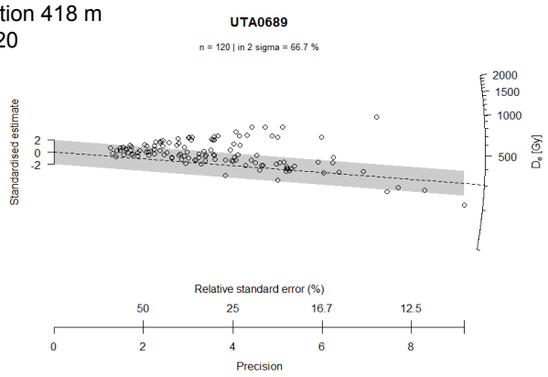
25MS-11
Elevation 368 m
n = 65

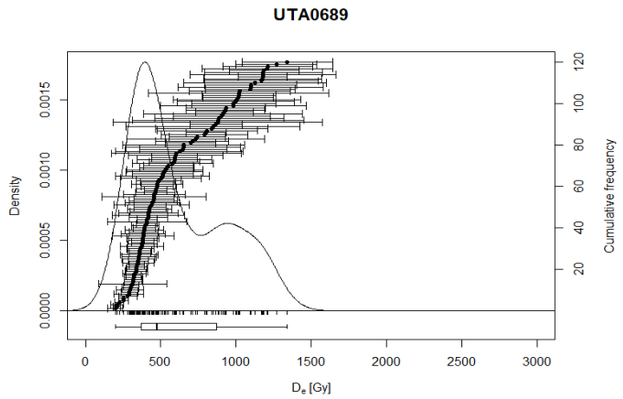




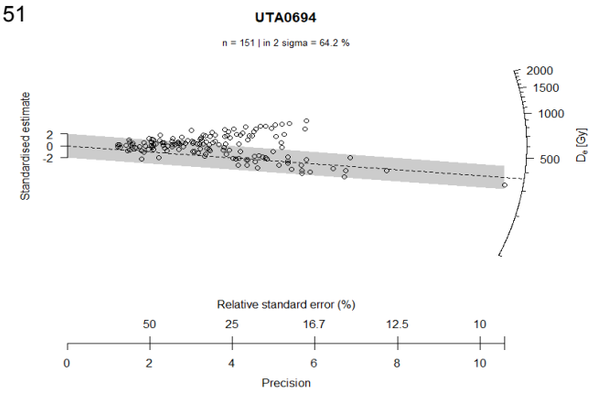
Extended Data Figure 2 | Radial plots (left) and KDE plots (right) for 3 of the 6 samples with resolved luminescence ages. KDE is kernal density estimate. Dashed line in the radial plots is the De value from the minimum age model, shaded gray area is ± 2σ error.

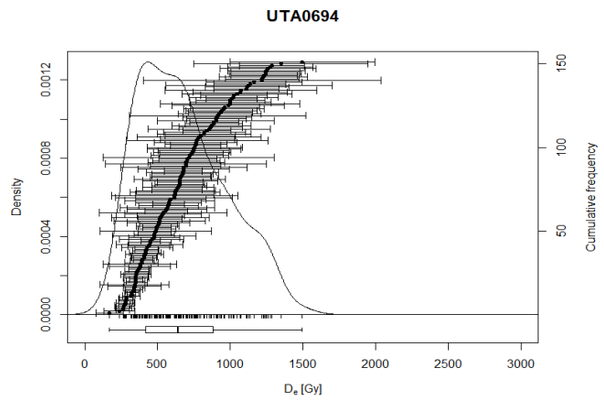
25MS-01
Elevation 418 m
n = 120



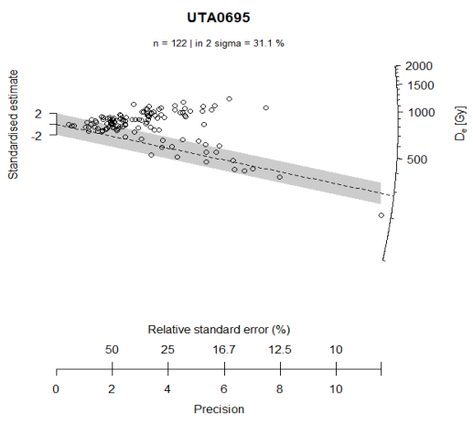


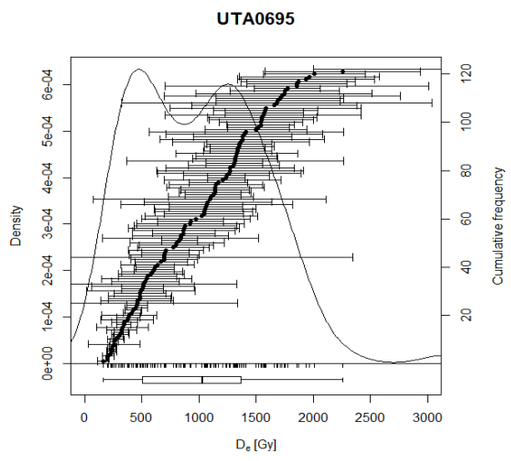
25MS-07
Elevation 405 m
n = 151



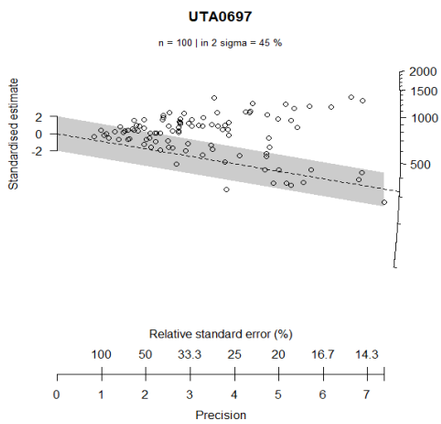


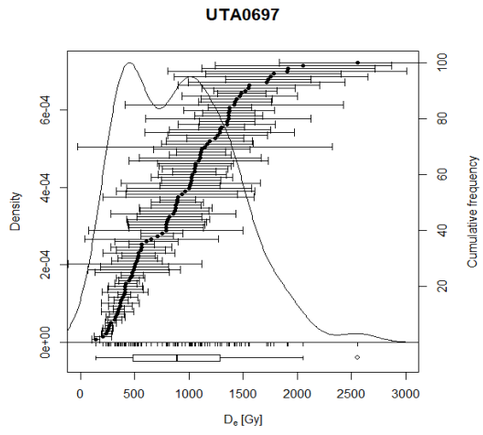
25MS-08
Elevation 1040 m
n = 122



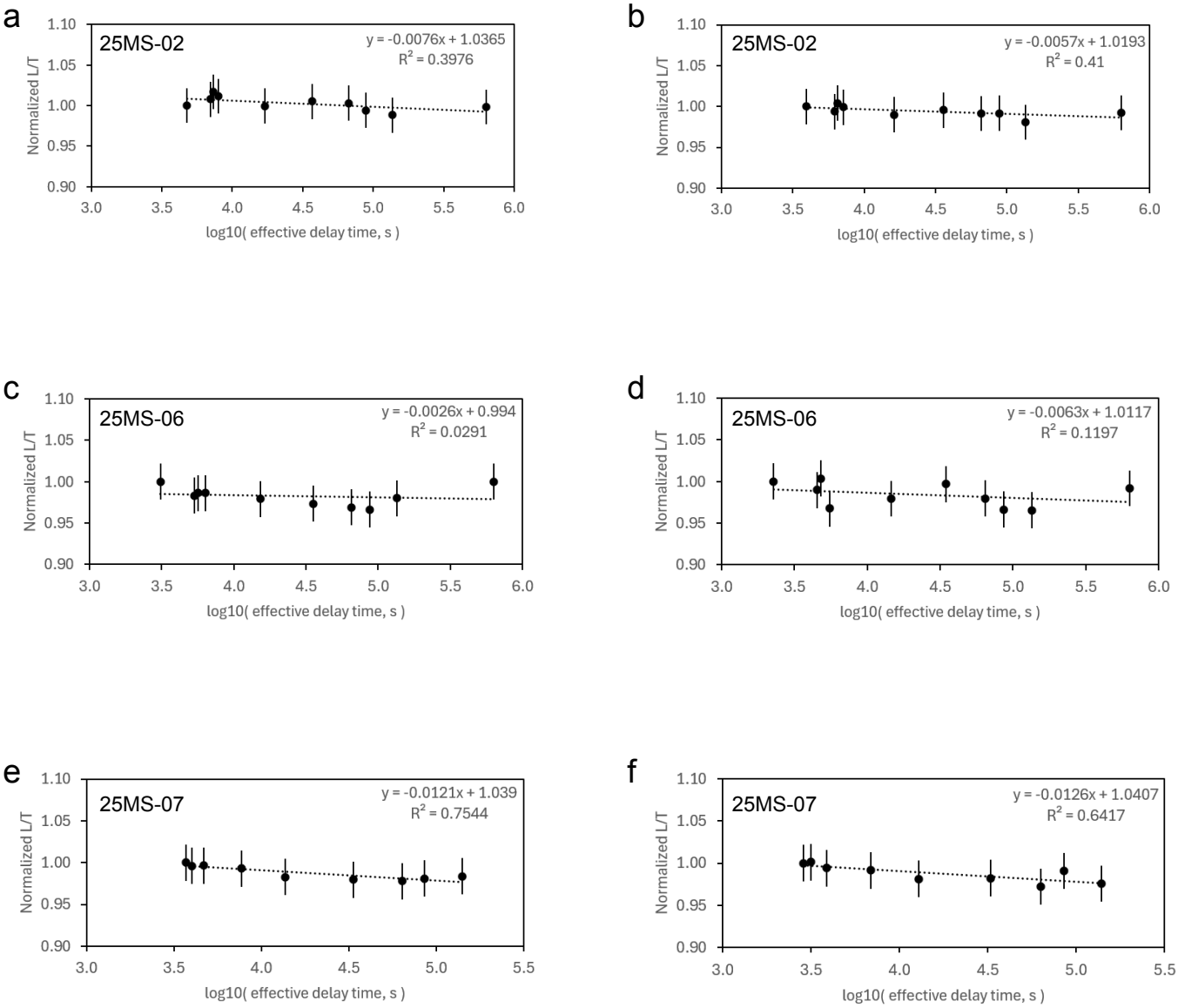


25MS-10
Elevation 107 m
n = 100

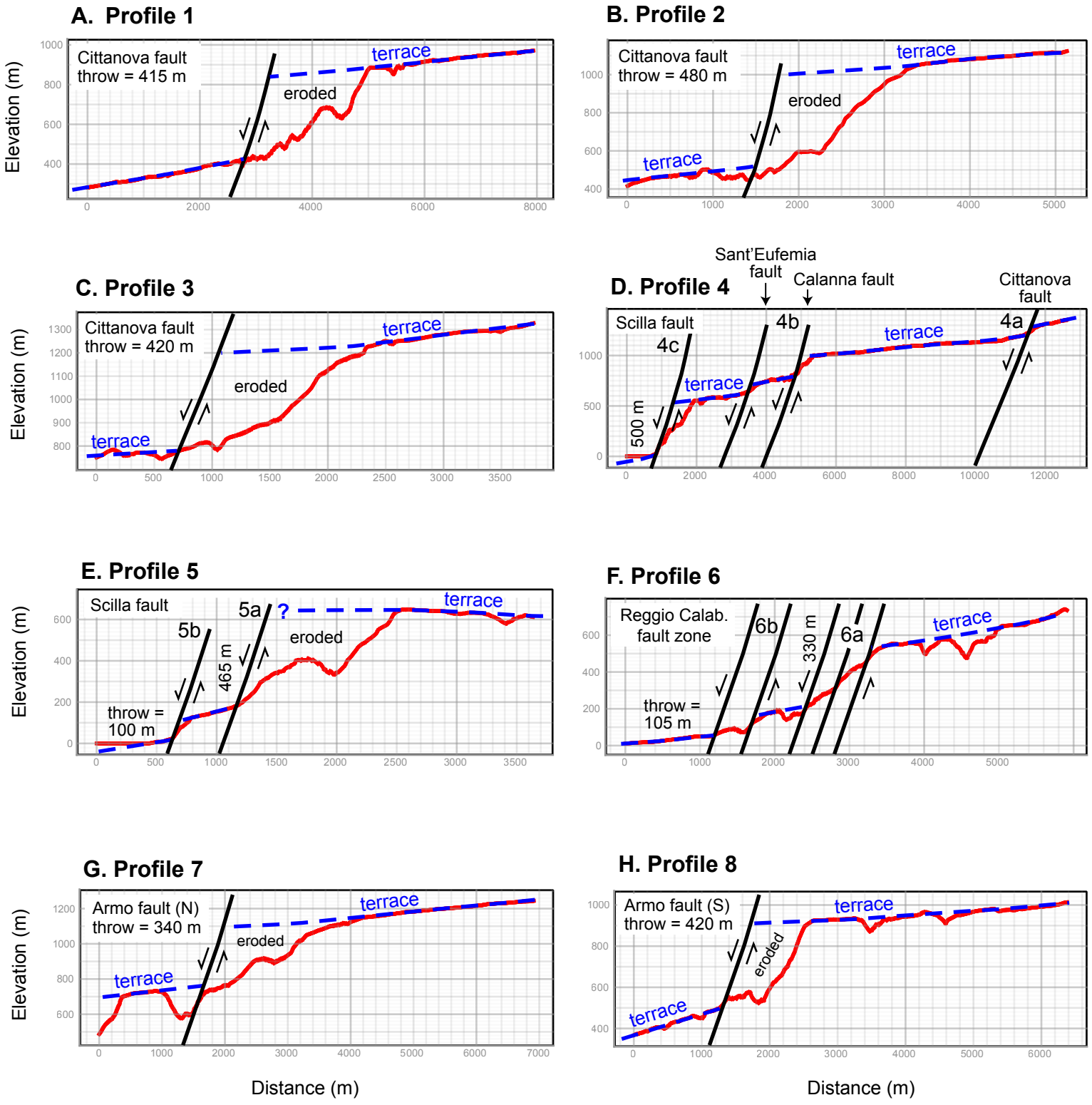




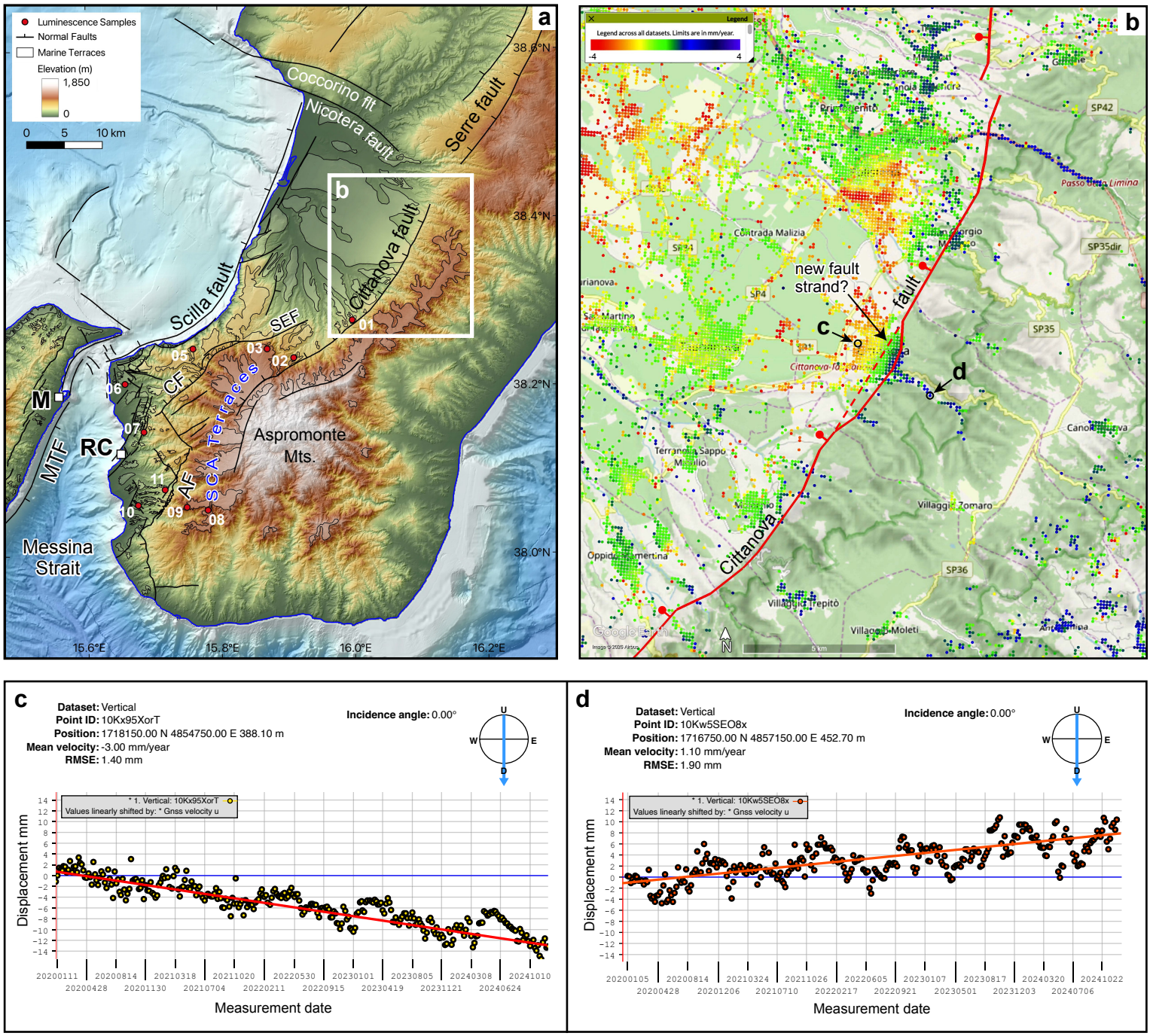
Extended Data Figure 3 | Radial plots (left) and KDE plots (right) for the 4 samples with saturated (unresolved) luminescence ages. KDE is kernal density estimate. Dashed line in the radial plots is the De value from the minimum age model, shaded gray area is ± 2σ error.



Extended Data Figure 4 | Representative fading results. (a, b) Sample 25MS-02. (c, d) Sample 25MS-06. (e, f) Sample 25MS-07. Each plot represents a single aliquot that was irradiated, preheated and then kept dark at room temperature for a range of delay times prior to measurement.



Extended Data Figure 5 | Fault-throw profiles for major active normal faults in the study area. Red lines are topography; blue dashed lines are variably incised marine terraces. Profile locations are shown in Fig. 4. Calculated fault-throw rates vary from 0.8 to 4.2 mm yr^{-1} (see Table 1).



Extended Data Figure 6 | Ground deformation in the vicinity of the Cittanova fault from the EGMS database (European Ground Motion Service: https://egms.land.copernicus.eu/). **(a)** Map modified from Fig. 1 showing location of map in b. **(b)** Map of the central to northern Cittanova fault showing the spatial pattern of vertical deformation derived from Sentinel-1 satellite data using the InSAR method. The data show a systematic change in vertical rate over a distance of ~1.5-2.5 km across the fault in several locations where data exist. Point locations for time series in c and d are shown. **(c)** Time series of vertical change for a representative point in the hanging wall of the Cittanova fault, mean velocity is -3.0 mm/yr. **(d)** Time series of vertical change for a representative point in the footwall of the Cittanova fault, mean velocity is +1.1 mm/yr. The difference in vertical rate between hanging wall and footwall locations over a period of 4 years is roughly 3.0–4.5 mm/yr, similar to the long-term post-120 ka fault-throw rate calculated for this fault (Table 1; Extended Data Fig. 5). The InSAR data also reveal unexplained variations that likely are related to complex interactions between short- and long-term deformation, changes in groundwater, surface mass movements, and human influence (e.g., ref 39). Similar variations in vertical motions along the Armo fault suggest a need for future work on this problem.

Extended Data Table 1. Location, Water Content, and Dose Rate Data for Analysed Samples

Field code	Lab code	Lat. (°N)	Lon. (°E)	Elev. (masl)	Over-burden (m)	U (ppm)*	Th (ppm)*	K (wt.%)*	Rb (ppm)*	Water cont. (%)	Geologic dose rate (Gy/ka)**
25MS-01	UTA0689	38.27908	16.00016	418	5.0	1.38	5.2	2.0	84.0	5.3	3.404 ± 0.135
25MS-02	UTA0690	38.23496	15.91138	701	21.0	2.29	9.3	2.8	115.0	12.2	4.333 ± 0.158
25MS-03	UTA0691	38.24564	15.87137	886	2.5	2.14	9.4	3.1	130.0	24.6	4.258 ± 0.152
25MS-05	UTA0692	38.24619	15.75951	597	3.3	1.67	10.0	2.5	106.0	7.8	4.242 ± 0.154
25MS-06	UTA0693	38.20470	15.65674	118	4.0	1.26	7.9	2.5	93.2	4.8	4.076 ± 0.153
25MS-07	UTA0694	38.14762	15.68477	405	2.0	1.16	6.0	2.6	113.0	4.7	4.012 ± 0.154
25MS-08	UTA0695	38.05434	15.78040	1040	4.0	1.21	5.8	1.6	69.1	8.0	2.993 ± 0.123
25MS-09	UTA0696	38.05801	15.74886	955	5.6	2.58	6.4	1.6	75.7	15.3	3.162 ± 0.125
25MS-10	UTA0697	38.06052	15.67550	107	4.0	1.73	6.1	1.7	75.2	1.6	3.401 ± 0.133
25MS-11	UTA0698	38.07885	15.71605	368	16.0	1.53	8.0	2.0	94.7	7.3	3.517 ± 0.137

* Elemental concentrations measured with ICP-MS and ICP-OES by SGS Canada. 5% relative standard error assumed.

** Calculated with the DRAC online calculator (Durcan et al., 2015) assuming an internal K content from Huntley and Baril (1997)

Note: Sample 25MS-04 is omitted because it is highly oxidized and was not analyzed for this study.

Extended Data Table 2. Equivalent Dose and Fading-Corrected Luminescence Ages

Field code	grains accepted / grains measured	OD (%)	Equivalent dose (Gy)*	Geologic dose rate (Gy/ka)	Uncorrected age (ka)	Fading corrected age (ka)**
25MS-01	120 / 300	44	334.9 ± 31.9	3.404 ± 0.135	90.0 ± 9.10	saturated
25MS-02	120 / 300	47	293.1 ± 27.0	4.333 ± 0.158	64.4 ± 5.89	116.7 ± 22.64
25MS-03	80 / 300	44	304.1 ± 34.9	4.258 ± 0.152	62.0 ± 7.39	123.6 ± 25.56
25MS-05	123 / 300	47	288.0 ± 28.3	4.242 ± 0.154	61.7 ± 6.17	118.4 ± 23.99
25MS-06	148 / 300	44	277.2 ± 23.6	4.076 ± 0.153	51.2 ± 5.80	109.7 ± 17.59
25MS-07	151 / 300	40	380.1 ± 30.8	4.012 ± 0.154	89.3 ± 7.44	saturated
25MS-08	122 / 300	61	307.4 ± 29.8	2.993 ± 0.123	94.3 ± 9.18	saturated
25MS-09	197 / 300	57	249.1 ± 10.8	3.162 ± 0.125	72.9 ± 7.53	127.3 ± 18.30
25MS-10	100 / 300	56	344.0 ± 36.4	3.401 ± 0.133	95.2 ± 10.10	saturated
25MS-11	65 / 300	51	247.0 ± 30.3	3.517 ± 0.137	66.4 ± 7.89	119.4 ± 24.25

* Three-parameter minimum dose model (Galbraith et al., 1999), assuming an overdispersion of 20% (Arnold and Roberts, 2009)

** Calculated using the Kars et al. (2008) model quantified by Guralnik and King (2026)